

INVESTIGATION OF  
LARGE STONE-MODIFIED ASPHALT MIXES  
USING THE MARSHALL METHOD

Part of

*PERMANENT DEFORMATION (RUTTING) CHARACTERISTICS  
OF BINDER-AGGREGATE MIXTURES CONTAINING CONVENTIONAL  
AND MODIFIED ASPHALT BINDERS*

*PHASE II*

*of*

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## INTRODUCTION

"Permanent Deformation (Rutting) Characteristics of Binder-Aggregate Mixtures Containing Conventional Asphalt and Modified Binders" is a joint research project involving the University of California, Berkeley (UCB) and Montana State University (MSU). The UCB portion of the study is supported by the California Department of Transportation (Caltrans), while the MSU portion is funded by the Montana Department of Highways (MDOH).

The investigation of asphalt binders at Montana State University began in 1988-89, during which time six modifiers were laboratory tested for MDOH. The results of the physical tests led to the selection of two modifiers, Polybilt and Kraton, from Exxon and Shell Chemical Companies, for further evaluation in field experimental pavements. During the following year, 1989-90, MDOH and MSU worked to establish an experimental project. The project was let to bid in August, 1990, and will be constructed in the 1991 construction season.

Caltrans entered the investigation of modified asphalt binders in 1989-90 by funding UCB and MSU in the first phase of this rutting study. Both UCB and MSU used the same binders, Montana produced Cenex and Conoco asphalt, in unmodified form and modified with Polybilt and Kraton. Aggregates were also used from the same source in the Yellowstone River of eastern Montana. With these materials, MSU performed extensive testing with the Marshall Method of mix design to assure applicability with

modified asphalt. UCB utilized its California Hveem Method of design together with creep and repeated load tests. Results, comparisons and evaluation of Phase I will be submitted in one report following the completion of Phase II.

Phase II, 1990-91, of the joint rutting study brought MDOH in as a funding partner with Caltrans. UCB is continuing its creep and loading studies in an effort to answer questions about the propensity of modified binder to fatigue and crack, even though improvements in "rutting performance" may be attained.

Phase II at MSU has the objective of investigating the performance of binder-aggregate mixtures, as before, but with inclusion of large-stone sizes up to 1/2 inches. The source of the large stone fraction of the aggregate is from the Yellowstone River, but from a different pit than the 3/4-inch minus aggregates. Otherwise, all materials are the same as used in Phase I and 1988-89. In addition, the conventional mixes of Phase I (3/4-inch maximum size) are being evaluated to include the use of hydrated lime mineral filler. Conventional size mixes are also being subjected to the Lottman Test to evaluate the moisture susceptibility of the modified binders. Asphalt tests were run to check the consistency of the asphalt properties of both modified and unmodified asphalts.

The results are presented in three sections. Section one covers the physical tests on 1990 modified asphalt. These tests were performed primarily to check the consistency of the physical properties of 1990 modified asphalt with 1988 and 1989 asphalt.

Section two involves all tests on conventional 3/4-inch maximum size aggregate with 4-inch molded specimens. There are two tests in this section; the effects of mineral filler on modified asphalt mixes and Lottman test, the resistance of compacted bituminous mixtures to moisture induced damage (ASHTO T283-85).

Section three concerns all tests performed on large stone mixes with 1/2-inch maximum size aggregate conducted on 6-inch molded specimens.

### Background

During 1988-89, the initial research on asphalt modifiers was performed at MSU (2). It was found that three modifiers, Kraton 4141G from Shell Chemical and Polybilt polymer 2 and 7 from Exxon Chemical, improved the asphalt properties to a greater degree than the other modifiers tested. Kraton is a thermoplastic block copolymer rubber, while Polybilt is a copolymer of ethylene vinyl acetate.

In the Phase I of this joint study (1989-90) of the mix design, two conventional Montana 1989 asphalts, Cenex (Laurel) and Conoco (Billings), and four modified asphalts (Cenex/Kraton; Cenex/Polybilt; Conoco/Kraton and Conoco/Polybilt) were used. These two asphalt sources, Conoco and Cenex were selected because they represent the physical testing parameter extremes of the modified asphalts that were tested in 1988-89. 120/150 penetration grade asphalts were selected for modification, since that grade of asphalt has, shown to have better "low temperature

susceptibility" characteristics than the harder 85/100 penetration grade asphalt typically used in Montana pavements. Samples of the same aggregate, conventional asphalts, and modified asphalts were also used in the Soil Mechanics and Bituminous Material Laboratory of University of California, Berkeley.

Prior to beginning the Marshall tests for Phase II, the asphalts of 1990 were physically tested for conformance to 1988 and 1989 asphalts. The test results indicated that the physical test parameters of both unmodified and modified asphalts from 1988, 1989 and 1990 are essentially the same.

Using the established Marshall mix design procedure for 3/4-inch aggregate-asphalt mixes, extensive tests were performed during Phase I to assure that the method is applicable to modified asphalt. It was determined that the same mix design procedures could be used for the modified asphalt. The following is a summary of findings of Phase I:

1. Fine (minus #200 size) aggregate in the mix can cause large variations in the Marshall test parameters.
2. Standard deviation of the results can be an indicator to the accuracy of the test parameters.
3. Split aggregate sampling does not always assure uniform mix of the aggregate components, causing greater variability between test results.
4. Kraton modified Cenex asphalt improved the Marshall test data to some extent. However, the improvement may be within the

range of testing variability for the Marshall test procedure.

5. A measured aggregate gradation for each sieve size results in a uniform sample composition and gives a better result.

6. Randomization of the test sequences can minimize the effects of unaccounted variables such as operators, temperature, etc..

7. An automatic recorder for plotting the load/deformation curve during the stability test is being used, satisfactorily.

### Literature Review

The rutting in asphalt concrete pavements is a pressing issue presently facing the highway agencies. The Western Association of State Highway and Transportation Officials (WASHTO) stated that the State materials engineers do not feel that the present procedures and specification fully address the rutting problem. The general feeling is that the present state-of-the-art in materials testing relating to rutting needs to be upgraded through basic research.

The current standard mix design procedures (Marshall and Hveem) both use 4 inch diameter molds, which cannot handle aggregates larger than 1 inch due to edge effects. This has limited the use of aggregates larger than one inch. Thus, the design of the mix is dictated by the mold size and not the pavement requirements.(3)

The use of large stone mixes is not new, Warren Brothers

Company had a patent issued in 1903 which specified a top size aggregate of three inches. Most companies started to use small stone mix to avoid infringement upon the patent, and such use is still prevalent today; although the Warren Brothers patent expired decades ago.(4)

According to Acott(3), the dense graded material is an aggregate blend that primarily develops strength from aggregate interlock and the viscosity of the binder. The introduction of large stone increases the volume concentration of aggregate (100-VMA) percent in the mix, which in turn improves its bearing capacity. The mix is characterized by high stability and air void levels typically between 4 and 6 percent.

Large stone asphalt treated bases were at one time the backbone of many state specifications, but over the years they have been replaced with finer mixtures. ASTM D3515 provides an example of typical grading envelopes for 1 1/2 inch nominal maximum size material.

The objective of using large stone mixture is to change the basic structure of the mix such that the traffic load is supported by direct stone on stone contact.(3)

These concepts are not new, but they are not being applied currently due to various factors. In fact, it is interesting to look briefly at the history of developments. Large stone penetration macadam, and later, plant mix macadam mixtures, were popular from the turn of the century through the 1950s.(3)

The National Asphalt Pavement Association (NAPA) has

categorized large stone hot mix asphalt mixture (HMA) into a family of three different products, each with different attributes: 1) Uniformly graded 2) Stone filled and 3) Open graded.(4)

In the study conducted to determine the relationship between asphalt mixtures properties and maximum aggregate size and to compare differences in test results between 4 and 6 inch diameter specimens for the mixes tested, Brown and Bassett(5) found that increasing the size of the largest aggregate in a gradation will increase the mix quality with respect to creep performance, resilient modulus, and tensile strength, but will not have a significant effect on Marshall stability. A higher flow value was observed for mixes having larger maximum size aggregate.(5)

Tighter control on the minus No. 200 material of the mixes should be exercised in future research relating to the effect of aggregate on the performance of a mix.(5)

The mix with maximum aggregate size will provide better performance if correctly designed and placed. Steps should be taken to standardize the use of 6-inch laboratory samples. This study indicated that these samples are more reproducible and the results are more indicative of observed performance. Four inch diameter samples are satisfactory for maximum aggregate size less than 1 inch.(5)

The resilient modulus data indicated that a large stone asphalt mix pavement layer offers a higher level of structural capacity when compared with a conventional hot mix asphalt layer

of the same thickness. Therefore, large-stone mixes can be cost competitive in terms of their added structural capacity combined with their lower optimum asphalt content.(6)

## Materials

### Asphalt

Samples of 120/150 penetration grade asphalt cement were obtained from the Cenex Refinery in Laurel and the Conoco Refinery in Billings. The two refineries were observed to be the most diverse during the initial modifier study, and thus, were selected for the first phase of the rutting study. The same asphalts were also used in the second phase. Both asphalts were modified by the manufacturers, as described below, and then shipped to UCB, and MSU.

### Kraton Modified Asphalt

Kraton rubber-asphalt mixtures were prepared by Shell Development Company utilizing 6 percent neat Kraton D4141G. Each source of asphalt, Cenex and Conoco, was modified with Kraton 4141G polymer. Kraton thermoplastic rubber polymers are a unique class of rubber designed for use without vulcanization. They differ fundamentally in molecular structure from the typical plastic or commercial rubber (homopolymer or random copolymers) in that they are triblock copolymers with an elastomeric block in the center and a thermoplastic block on each end. They are readily soluble and thus are suited to the formulation of solvent-based adhesives. D4141G is linear SBS (Styrene-Butadiene-

Styrene) block copolymers similar in molecular architecture to D1101. The "D" designation refers to either SBS or SIS polymers. The first "4" identifies the polymer as containing process oil usually a naphthenic/paraffinic type which is added to the polymer to aid in the mixing of the polymer into bitumen and/or to affect desirable changes in the physical properties of the final binder blend. D4141G contains about 29 percent oil. The designation G refers to the polymer being in the ground "powder" form, again for the purpose of decreasing blending time.

### Polybilt Modified Asphalt

Polybilt is an EVA, (Ethylene Vinyl Acetate), resin, and encompasses a large family of petrochemical polymers and polymer concentrates designed for asphalt modification by Exxon Chemical Company. Two polymers were used, Polymer #2 and Polymer #7; both are EVAs but differ in molecular weight and VA content. Polymer 2 was used for the asphalt from Cenex, and Polymer 7 for Conoco, at treat rate of 4 and 3.5 percent by weight, respectively. Conoco is more compatible with Polybilt than Cenex.(8)

### Aggregates

Selection of the aggregate was done after conferring with the MDOH materials personnel in Helena and Billings. Rutting problems in Montana are more pronounced in the eastern areas of the state and typically involve Yellowstone River(YR) gravel. The Billings District provided material from the E. E. St. John pit. The samples were obtained from stock piles of MDOH, and submitted in several sacks of three fractions: coarse, crushed fine, and

natural fine. The large stone aggregate was received from the Prince Paving Co., Forsyth, Mt. A large quantity of large stone aggregate was delivered by truck and stocked in the MSU yard. The source of gravel in both the Prince Paving Co., Forsyth, Mt. and St. Johns pit is the Yellowstone River valley.

### Mineral Filler

The hydrated lime mineral filler was used in both the conventional aggregates and large stone aggregates mix designs. Lime mineral filler is a known antistripping agent. The stripping of asphalt from aggregate surface is a complex physical - chemical process that results in early pavement distress. Lime increases the attraction between polar sites in the asphalt and aggregate surfaces. The lime mineral filler was obtained from Pete Lien & Sons, Inc., Rapid City, SD.

### Asphalt Tests

Standard asphalt tests such as penetration at 39.2°F and 77°F, kinematic viscosity, ring and ball softening point, and adhesion tests were conducted on the unmodified and modified asphalt. These tests were repeated on the residue of thin film oven tests. The purpose of conducting these tests was to check the conformity of the test parameter of the materials received in 1990 with those of 1989 and 1988 batches of materials, and also to see if the modification can be repeated to give uniform values year after year. The results of the tests are presented and discussed in subsequent sections.

The total number of asphalt tests conducted are as follows:

Penetration at 77°F	108
Penetration at 39.2°F	108
Ring and Ball	24
Kinematic Viscosity	24
Adhesion	<u>24</u>
Total	288

### Procedure

The AASHTO standard method of test procedure was followed in conducting the asphalt tests. The AASHTO test number and test title are as follows:

<u>AASHTO</u>	<u>Test Title</u>
<u>Designation</u>	
T49 - 80	Penetration of Bituminous Material.
T53 - 81	Softening Point of Asphalt (Bitumen) and Tar in Ethylene Glycol (Ring & Ball).
T201-80	Kinematic Viscosity of Asphalt at 275F
T179 - 80	Effect of Heat and Air on Asphalt Materials (Thin Film Oven Test).

### Results and Observations

The asphalt test results are shown in Table A1. It was observed that the asphalt test parameters of the modified asphalt are higher than the unmodified asphalt, both before and after thin film oven tests. The values of the ring and ball softening point of the modified asphalt are higher than those of the

1990 Asphalt

Table A1. Asphalt Test Results on 1990 Unmodified and Modified Asphalt.

Tests	Cenex Unmodified	Kraton Modified Cenex	Polybilt Modified Cenex	Conoco Unmodified	Kraton Modified Conoco	Polybilt Modified Conoco
Ring & Ball Softening Pt. in F	108.00	173.00	128.00	109.00	176.00	154.00
Penetration at 39.2 F in dmm	39.56	42.00	33.00	39.11	36.78	27.11
Penetration at 77 F in dmm	145.10	80.00	90.67	136.40	81.78	75.56
Thin Film Oven Test in grams	0.152	0.082	0.648	0.022	0.033	0.016
Kinematic Viscosity in CStoke	249.84	1309.50	471.79	204.74	1119.34	450.40
Adhesion in %	78.00	80.00	85.00	77.50	77.50	85.00
After TFOT						
Ring & Ball Softening Pt. in F	114.00	168.00	138.00	106.00	183.00	146.00
Penetration at 39.2 F in dmm	30.22	38.00	26.67	26.78	29.00	23.75
Penetration at 77 F in dmm	91.78	71.78	64.33	93.67	71.88	60.50
Kinematic Viscosity in CStoke	303.36	1446.26	562.19	267.36	1140.43	565.95
Marshall Stability in lbs. *	4687.00	4316.00	4487.00	4195.65	4618.18	4354.55
Marshall Flow in 1/100 inch *	14.00	16.15	14.43	12.10	14.44	13.71
Unit Weight in gm/c.c. *	2.386	2.377	2.387	2.397	2.376	2.384
Percent Air Voids *	3.79	2.86	3.70	3.00	2.83	3.06

\* The Marshall test results are based on 6-inch molded specimen at optimum asphalt content

unmodified asphalt, indicating improvement in high temperature susceptibility. The penetration values at 39.2°F and 77°F for the modified asphalt are low compared to those of the unmodified asphalt.

#### Comparison of the Results Between 1988, 1989 and 1990 Tests

The asphalts received in 1990 from Cenex and Conoco were tested for consistency of test parameter values with that of 1989 and 1988 test parameters. Both asphalts were modified with the same percent of Polybilt (4% of Polymer 2 for Cenex and 3.5% of Polymer 7 for Conoco) as was mixed for the 1989 and 1988 asphalts. Similarly, both the asphalts were modified with 6% Kraton. The comparison of test results is demonstrated in Table A2 for Cenex and Table A3 for Conoco.

It is observed from Tables A2 and A3 that there is little difference in the results of penetration at 39.2°F, and 77°F and the ring and ball softening point, in both before and after the thin film oven test over three years of unmodified Cenex and Conoco asphalt. Similar results were observed for Polybilt modified Cenex and Conoco, except for the penetration value of Polybilt modified Conoco at 77°F for 1989 asphalt, which was lower compared to 1988 and 1990 values. The comparison of the test results before and after thin film oven tests are illustrated in a bar chart for unmodified Cenex, Kraton modified Cenex (Ke-Ce), and Polybilt modified Cenex (Po-Ce) in Figures, A1 for penetration at 39.2°F, A2 for penetration at 77°F, A3 for ring and ball softening point, and A4 for kinematic viscosity.

1990 Asphalt

Table A2. Comparison of Test Results of Unmodified and Modified 120/150 Asphalts between 1990, 1989 and 1988 Asphalt and 85/100 1988 Asphalt.

Asphalt	Cenex Unmodified			Kraton Modified Cenex			Polybilt Modified Cenex			85/100 Cenex
	1988	1989	1990	1988	1989	1990	1988	1989	1990	1988
Ring & Ball Softening Pt. in F.	114.80	109.50	108.00	163.40	167.00	173.00	133.70	134.00	128.00	116.60
Penetration at 39.2 F in dmm.	42.00	48.00	39.56	37.00	38.83	42.00	39.00	41.60	33.00	24.00
Penetration at 77 F in dmm.	137.00	137.50	145.10	79.00	77.20	80.00	91.00	95.90	90.67	89.00
Thin Film Oven Test in gram.	0.204	0.134	0.152	0.190	0.106	0.082	0.201	0.092	0.648	0.186
Kinematic Viscosity in CStoke.	235.80	NA	249.84	1089.20	NA	1309.50	387.60	NA	471.79	317.90
Adhesion in Percent.	80.00	NA	78.00	90.00	NA	80.00	75.00	NA	85.00	65.00
After TFOT										
Ring & Ball Softening Pt. in F.	116.50	117.50	114.00	162.50	168.00	168.00	137.30	134.00	138.00	124.70
Penetration at 39.2 F in dmm.	31.00	30.00	30.22	35.00	28.20	38.00	29.00	29.30	26.67	29.00
Penetration at 77 F in dmm.	85.00	85.30	91.78	64.00	61.56	71.78	59.00	60.20	64.33	54.00
Kinematic Viscosity in CStoke.	309.30	NA	303.36 x	1253.80	NA	1446.26 x	531.10	NA	562.19 x	426.00
Marshall Stability in lbs.	2400.00	2386.00	4687.50 x	3500.00	2357.00	4316.00 x	2230.00	2465.00	4487.72 x	2480.00
Marshall Flow in 1/100 inch. *	14.00	12.10	14.00 x	15.20	14.40	16.15 x	16.40	13.50	14.43 x	13.00
Unit Weight in gm/c.c.	2.387	2.388	2.386 x	2.370	2.365	2.377 x	2.383	2.386	2.387 x	2.332
Percent Air Voids.	3.00	2.70	3.79	3.80	3.01	2.86	3.00	2.64	3.70	3.50

\* The Marshall test results are based on 6-inch molded specimen at optimum asphalt content

1990 Asphalt

Table A3. Comparison of Test Results of Unmodified and Modified 120/150 Asphalts between 1990, 1989 and 1988 Asphalt and 85/100 1988 Asphalt.

Asphalt	Conoco Unmodified			Kraton Modified Conoco			Polybilt Modified Conoco			85/100 Conoco
	1988	1989	1990	1988	1989	1990	1988	1989	1990	1988
Ring & Ball Softening Pt. in F.	113.00	110.00	109.00	179.60	182.50	176.00	158.90	161.00	154.00	120.20
Penetration at 39.2 F in dmm.	40.00	41.20	39.11	36.00	37.56	36.78	34.00	33.90	27.11	30.00
Penetration at 77 F in dmm.	133.00	140.00	136.40	82.00	85.56	81.78	80.00	68.20	75.56	92.00
Thin Film Oven Test in gram.	0.017	0.043	0.022	0.463	0.069	0.033	0.004	0.004	0.016	0.023
Kinematic Viscosity in CStoke.	192.10	NA	204.74	1159.00	NA	1119.34	388.80	NA	450.40	262.50
Adhesion in Percent.	90.00	NA	77.50	85.00	NA	77.50	65.00	NA	85.00	55.00
After TFOT										
Ring & Ball Softening Pt. in F.	118.40	116.50	106.00	176.90	177.00	183.00	149.00	146.50	146.00	121.10
Penetration at 39.2 F in dmm.	31.00	37.67	26.78	39.00	20.10	29.00	26.00	27.30	23.75	19.00
Penetration at 77 F in dmm.	94.00	95.20	93.67	67.00	66.30	71.88	62.00	52.40	60.50	68.00
Kinematic Viscosity in CStoke.	237.10	NA	267.36 x	1158.40	NA	1140.43 x	459.90	NA	565.95 x	312.10
Marshall Stability in lbs.	2060.00	2340.00	4195.65 x	2418.00	2632.00	4618.18 x	2640.00	2636.00	4354.00 x	2680.00
Marshall Flow in 1/100 inch. *	8.40	11.54	12.10 x	15.00	15.25	14.44 x	13.60	15.15	13.71 x	13.60
Unit Weight in gm/c.c.	2.388	2.387	2.397 x	2.373	2.379	2.376 x	2.376	2.387	2.384 x	2.361
Percent Air Voids.	3.60	3.00	3.00	3.00	2.74	2.83	3.20	2.71	3.06	3.10

\* The Marshall test results are based on 6-inch molded specimen at optimum asphalt content

# Penetration at 39.2F—Cenex Mod. Asphalt 1988, 1989, & 1990— Before & After TFOT

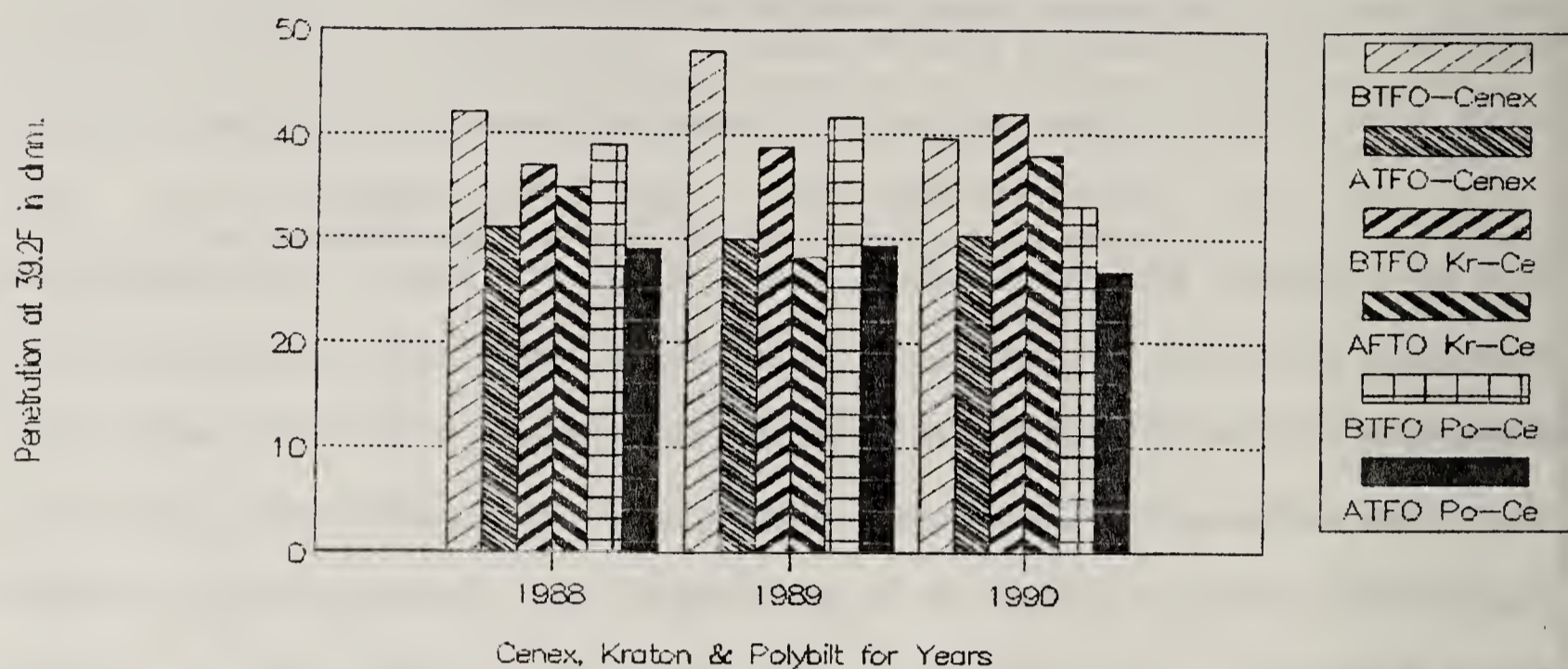


Figure A1. Penetration at 39.2F for Cenex

# Penetration at 77F — Cenex Mod. Asphalt 1988, 1989, & 1990— Before & After TFOT

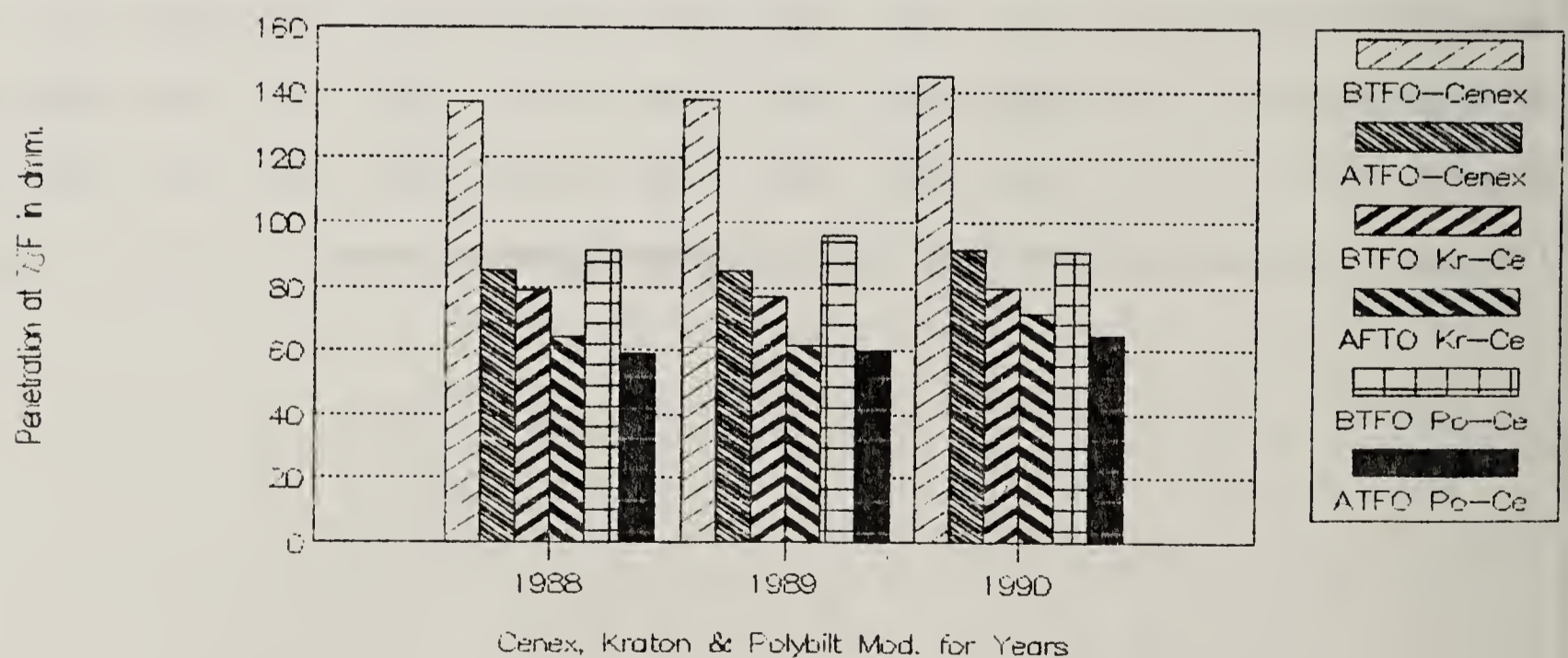


Figure A2. Penetration at 77F for Cenex

# Ring & Ball – Cenex Mod. Asphalt 1988, 1989, & 1990– Before & After TFOT

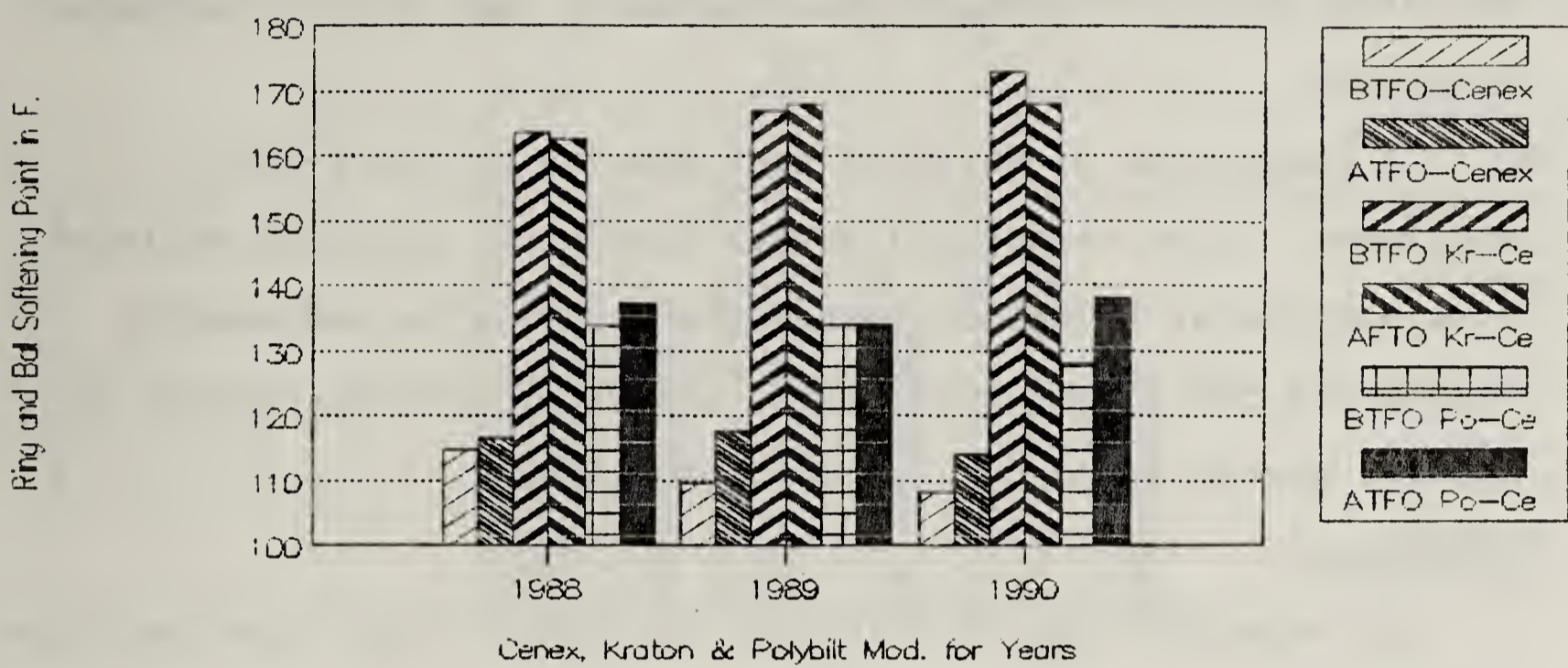


Figure A3. Ring & Ball for Cenex

# Kinematic Viscosity– Cenex Mod. Asphalt 1988 and 1990 – Before & After TFOT

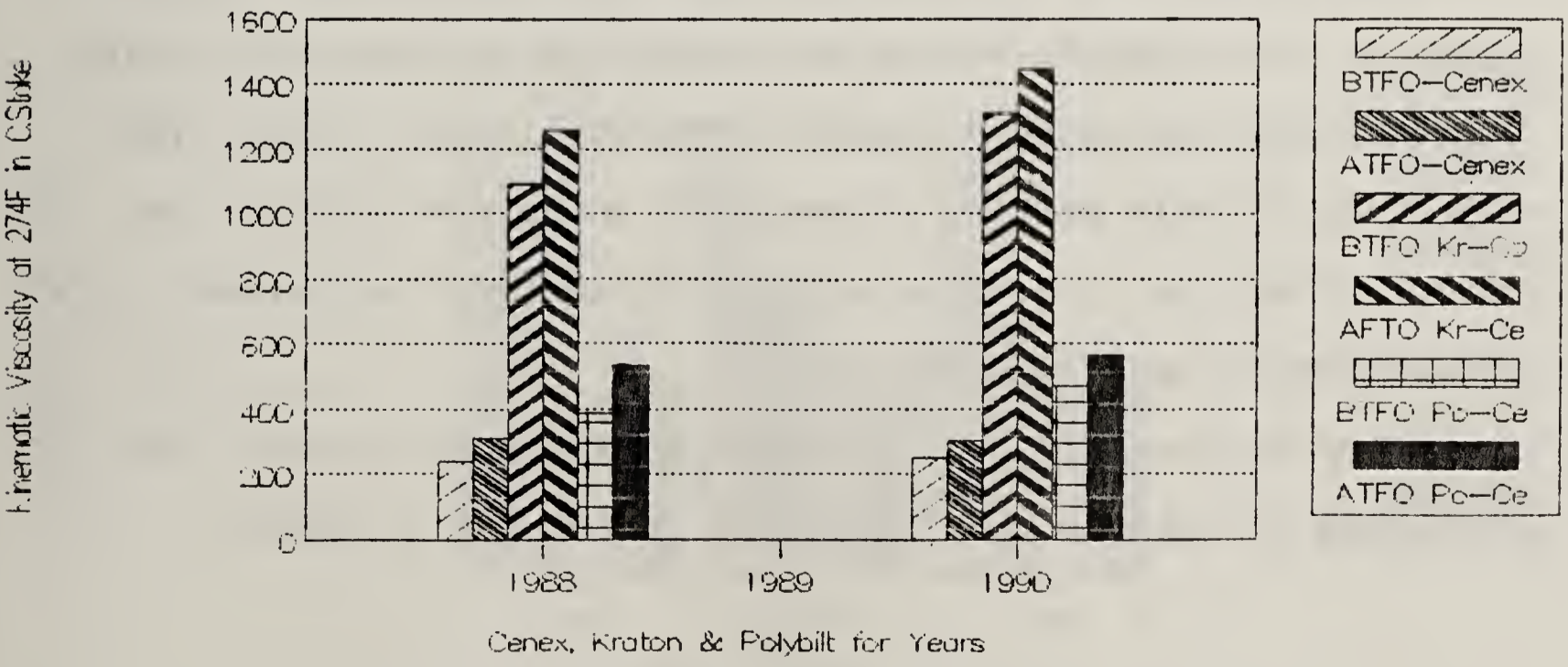


Figure A4. Kinematic Viscosity for Cenex

Similarly, the comparison of test results for unmodified Conoco, Kraton modified Conoco (Kr-Co), and Polybilt modified Conoco (Po-Co) are illustrated in Figures A5 for penetration at 32.9°F, A6 for 77°F, A7 for ring and softening point, and A8 for kinematic viscosity.

A comparison of Marshall test results of the 6-inch specimens (large stone) and 4-inch specimens (3/4-inch maximum size aggregate) revealed greater stability, flow and density values for the large stone mixes. Likewise, optimum percent of asphalt decreased for the large stone mixes.

### **Conclusion**

By observing the asphalt test results of 1990, 1989 and 1988 asphalt, it is concluded that the physical test parameter values of an asphalt from a single source do not change significantly. This is true for the modified asphalt with equal amounts of the modifier.

### **Effect of Mineral Filler in Modified Asphalt Mix**

This is an extension of the phase I research project. In Phase I, the Marshall method of mix design was performed using conventional aggregate gradation without mineral filler. The objective of this section of research is to investigate the effect of an additive, lime mineral filler, on the Marshall mix properties of modified asphalt.

Lime mineral filler is a known antistripping agent. The stripping of asphalt from aggregate surface is a complex

# Penetration at 39.2F—Conoco Mod. Asp. 1988, 1989, & 1990— Before & After TFOT

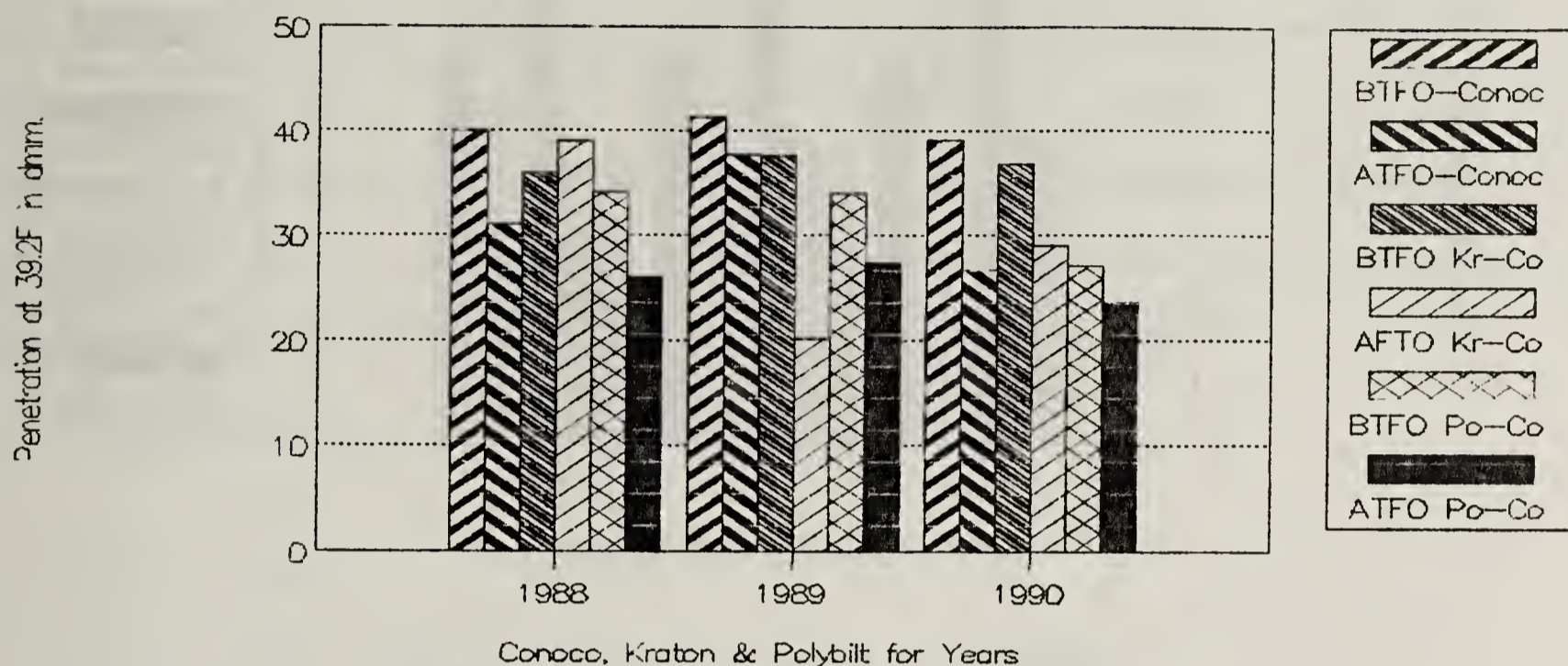


Figure A5. Penetration at 39.2F for Conoco

# Penetration at 77F—Conoco Mod. Asphalt 1988, 1989, & 1990— Before & After TFOT

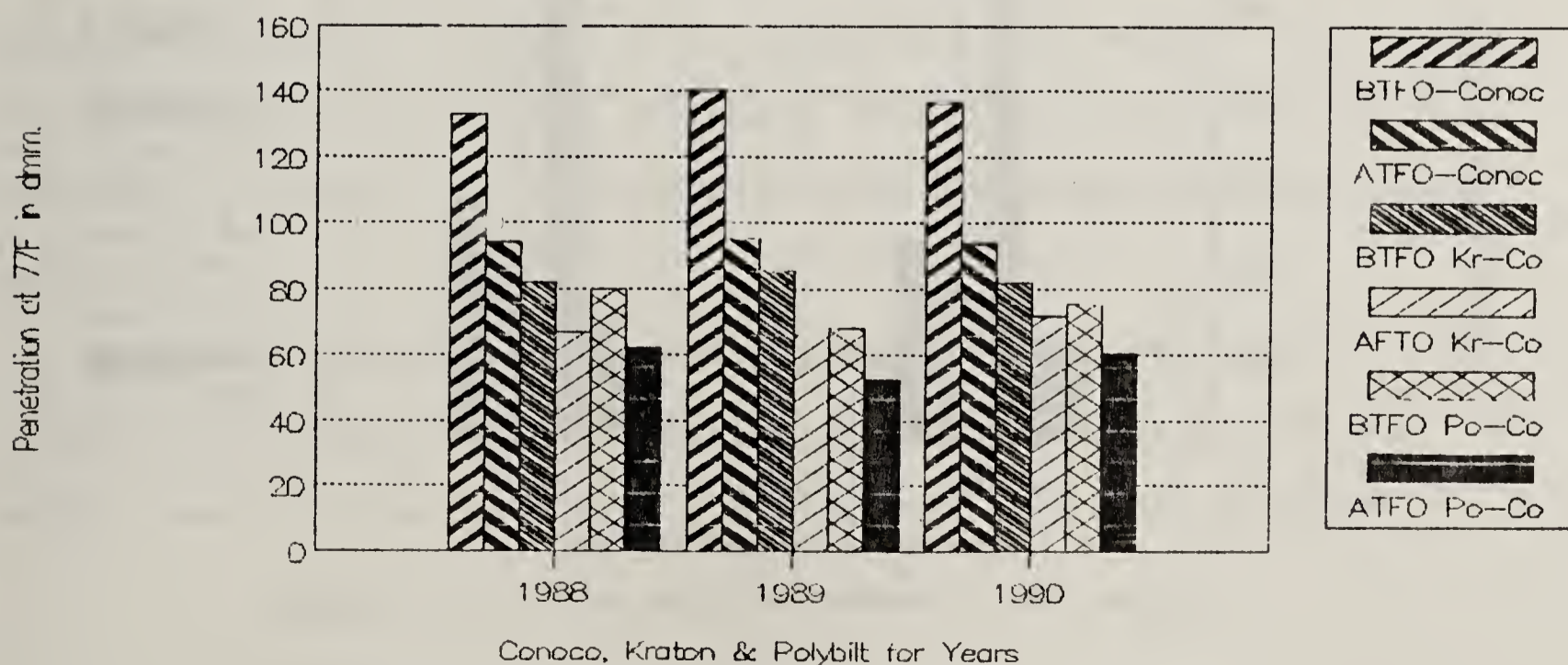


Figure A6. Penetration at 77F for Conoco

# Ring and Ball-Conoco Mod. Asphalt 1988, 1989, & 1990- Before & After TFOT

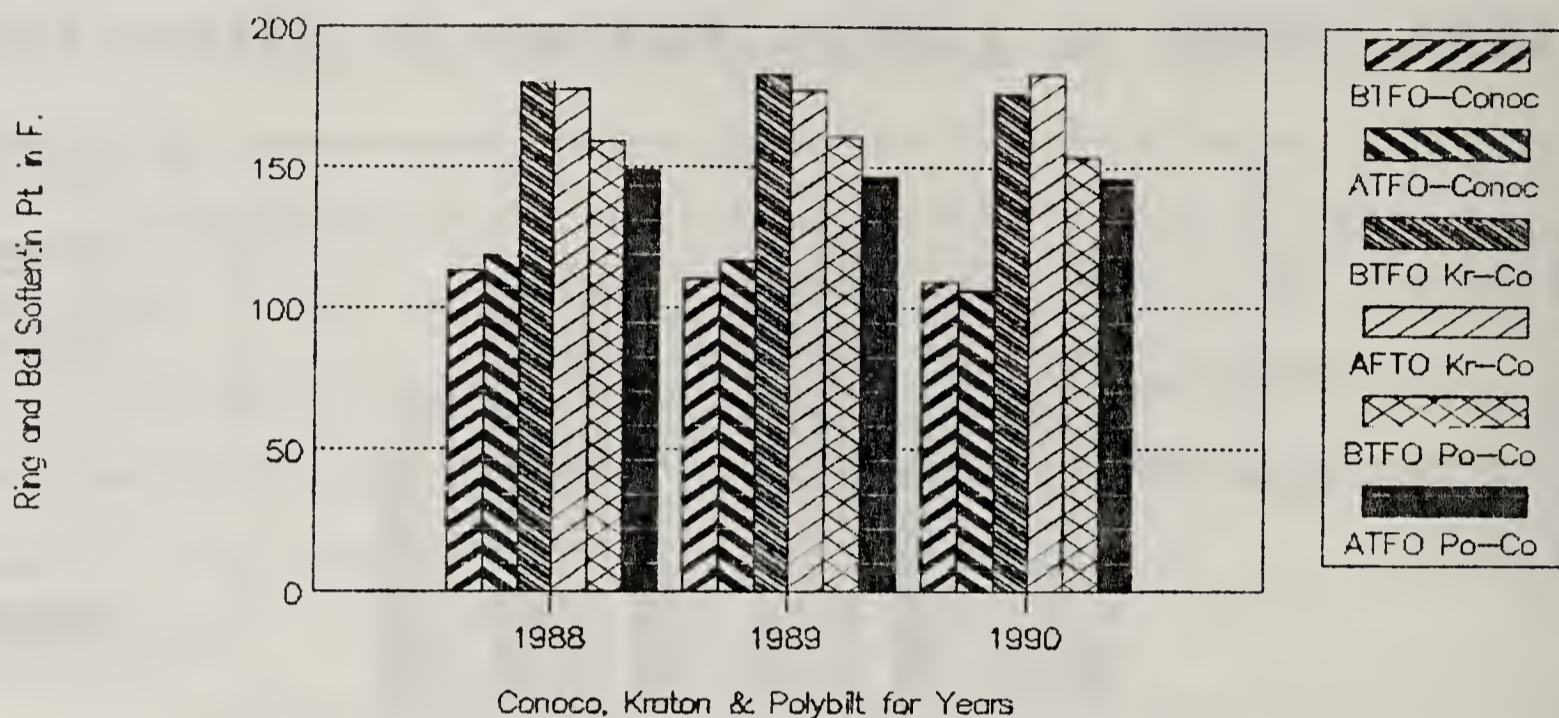


Figure A7. Ring & Ball for Conoco

# Kinematic Viscosity-Conoco Mod. Asphalt 1988 and 1990- Before & After TFOT

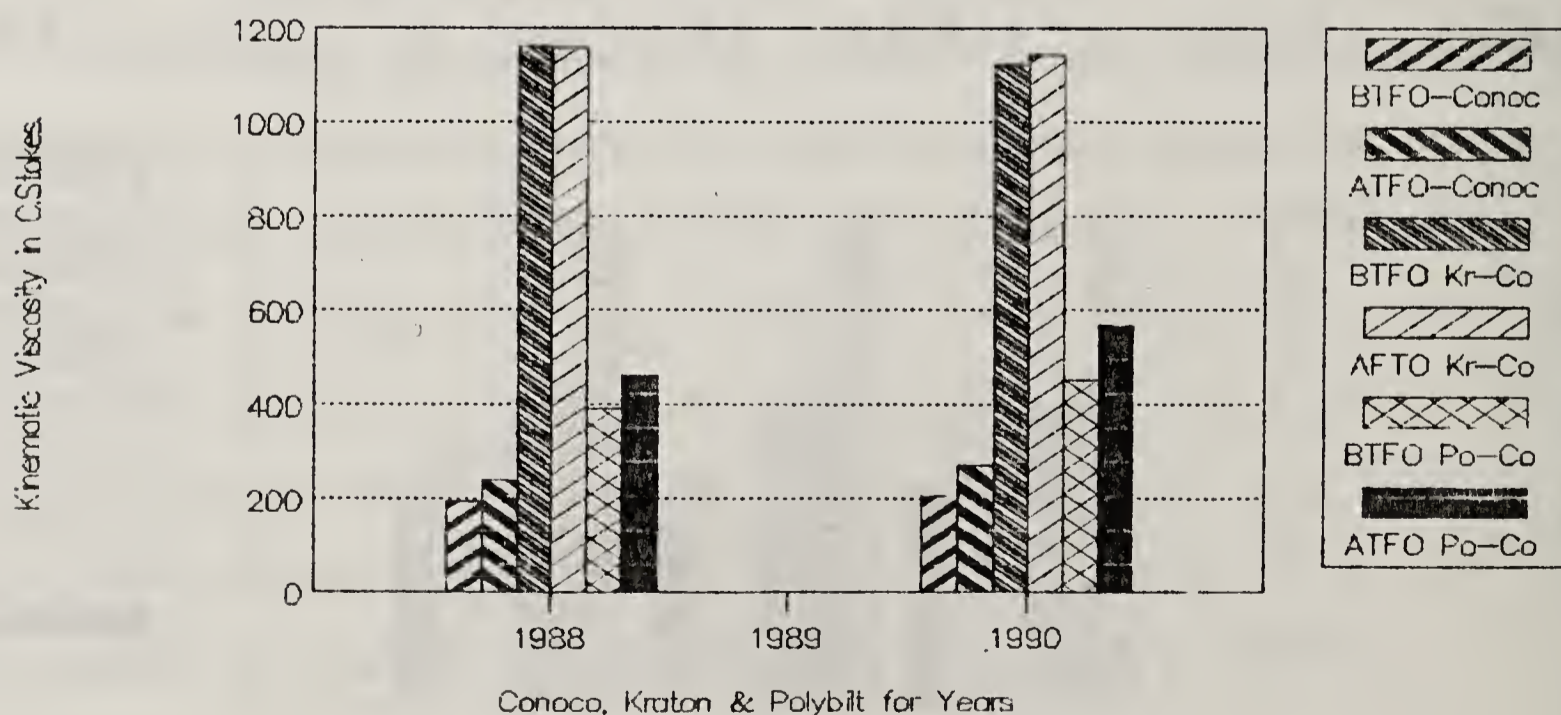


Figure A8. Kinematic Viscosity for Conoco

physical-chemical process that can result in early pavement distress. Lime increases the attraction between polar sites in the asphalt, and aggregate surfaces.(9)

The same aggregate, asphalt, and modified asphalt were used as in Phase I. The lime mineral filler was obtained from Pete Lien & Sons, Inc., Rapid City, SD. The mineral filler, 1.4 percent by weight of mix, was added to the aggregate and mixed thoroughly prior to heating to the mix temperature. The following aggregate gradations with mineral filler were used:

<u>Sieve Size</u>	<u>Percent Passing</u>
3/4"	100
1/2"	84.7
3/8"	73.4
#4	53.4
#10	37.2
#40	17.8
#200	6.2
Mineral Filler	1.4

A set of six four inch molded specimens at each of four different asphalt contents were prepared. The samples were tested for bulk specific gravity, Marshall stability and flow, and Rice specific gravity. The percent air voids was computed from these data.

The results of three samples were selected from six repetitions based on the closest stability, density, and air voids results. The data were analyzed for mean and standard

deviation and are presented in Tables F1 for unmodified and modified Cenex and F2 for unmodified and modified Conoco.

The Marshall test property curves for each modified and unmodified asphalt samples were drawn as shown in Appendix A. The optimum asphalt content of the mix was determined using the values obtained from these curves. At this asphalt content, properties of the mix, stability, unit weight, percent air voids, and flow were determined using figures in Appendix A. The optimum asphalt content for each asphalt and Marshall test properties at optimum asphalt content are presented in Table F3.

The optimum asphalt content for the mix design without mineral filler and Marshall test properties at optimum asphalt content were obtained from Phase I and are presented in Table F4 for comparison.

### **Results and observations**

It is observed from Table F3 and F4 that the optimum asphalt content of the mix with the mineral filler is lowered by about one percent. In the case of Kraton modified Cenex and Conoco and Polybilt modified Conoco, the optimum asphalt content is decreased by over 1.32 percent. This is illustrated in Figure F1.

Similarly, the test property values of the mix with mineral filler were observed to be improved in spite of lower optimum asphalt content. The stability is improved by 13 to 42 percent. The stabilities of Kraton modified Cenex and Conoco mix with mineral filler were improved most, by 42 and 36 percent, respectively. Polybilt modified Cenex and Conoco mix with mineral

Table F1. Marshall Test Results - Cenex with 3/4 inch Maximum Size Aggregates and Mineral Filler.

Tests	Unmodified Cenex 120/150 - 75 Blow Compaction				
Asphalt Content	4.00%	4.50%	5.00%	5.50%	6.00%
Mean Marshall Stability in lbs.	3000.00	3040.67	2981.83	2617.33	2472.67
Standard Dev. Marshall Stability	125.00	124.24	198.58	75.06	68.86
Mean Marshall Flow in 1/100 inch.	12.33	11.67	13.33	14.00	20.67
Standard Deviation Marshall Flow	0.58	0.58	0.58	1.00	1.15
Mean Bulk Specific Gravity	2.312	2.372	2.402	2.400	2.397
Standard Deviation Bulk Sp. Gr.	0.012	0.011	0.005	0.010	0.002
Unit Weight in Pcf.	144.27	148.01	149.88	149.76	149.57
Mean Rice Specific Gravity	2.502	2.498	2.423	2.453	2.429
Standard Deviation Rice Sp. Gr.	0.008	0.012	0.041	0.015	0.011
Mean Percent Air Voids	7.22	5.02	3.45	2.17	1.29
Standard Deviation % Air Voids	0.55	0.32	0.78	0.97	0.48
VMA*	18.02	16.34	14.83	14.90	15.46

Tests	Kraton Modified Cenex - 75 Blow Compaction			
Mean Marshall Stability in lbs.	2925.00	3376.33	3116.67	3073.67
Standard Dev. Marshall Stability	125.00	749.54	418.58	63.88
Mean Marshall Flow in 1/100 inch.	10.67	13.67	13.67	17.67
Standard Deviation Marshall Flow	0.58	1.53	0.58	1.15
Mean Bulk Specific Gravity	2.345	2.399	2.413	2.390
Standard Deviation Bulk Sp. Gr.	0.019	0.013	0.065	0.006
Unit Weight in Pcf.	146.33	149.70	150.57	149.14
Mean Rice Specific Gravity	2.401	2.456	2.453	2.428
Standard Deviation Rice Sp. Gr.	0.067	0.037	0.044	0.009
Mean Percent Air Voids	3.35	2.33	2.86	1.58
Standard Deviation % Air Voids	0.20	1.78	1.36	0.47
VMA*	16.41	14.03	13.98	15.25

Tests	Polybilt Modified Cenex - 75 Blow Compaction			
Mean Marshall Stability in lbs.	2916.67	3050.67	2685.67	2816.67
Standard Dev. Marshall Stability	301.39	30.00	15.95	65.43
Mean Marshall Flow in 1/100 inch.	11.67	12.33	13.33	15.67
Standard Deviation Marshall Flow	0.58	0.58	1.15	1.53
Mean Bulk Specific Gravity	2.363	2.384	2.400	2.409
Standard Deviation Bulk Sp. Gr.	0.012	0.004	0.008	0.009
Unit Weight in Pcf.	147.45	148.76	149.76	150.32
Mean Rice Specific Gravity	2.478	2.478	2.448	2.427
Standard Deviation Rice Sp. Gr.	0.029	0.003	0.005	0.014
Mean Percent Air Voids	4.64	3.82	1.96	0.71
Standard Deviation % Air Voids	0.66	0.22	0.33	0.40
VMA*	15.77	14.57	14.45	14.58

\* VMA values are based on assumed bulk specific gravity of aggregate = 2.651

Table F2. Marshall Test Results-Conoco with 3/4 inch Maximum Size Aggregates and Mineral Filler.

Tests	Unmodified Conoco 120/150 - 75 Blow Compaction				
Asphalt Content	4.00%	4.50%	5.00%	5.50%	6.00%
Mean Marshall Stability in lbs.	3200.00	3371.33	2957.33	2602.67	2560.00
Standard Dev. Marshall Stability	225.00	349.15	331.94	175.51	69.28
Mean Marshall Flow in 1/100 inch.	12.67	12.33	14.00	13.00	14.33
Standard Deviation Marshall Flow	1.53	1.53	1.73	0.00	0.58
Mean Bulk Specific Gravity	2.347	2.361	2.388	2.399	2.392
Standard Deviation Bulk Sp. Gr.	0.008	0.029	0.004	0.016	0.008
Unit Weight in Pcf.	146.45	147.33	149.01	149.70	149.26
Mean Rice Specific Gravity	2.481	2.476	2.462	2.450	2.427
Standard Deviation Rice Sp. Gr.	0.024	0.023	0.004	0.007	0.013
Mean Percent Air Voids	5.39	4.62	2.98	2.09	1.47
Standard Deviation % Air Voids	0.76	1.71	0.26	0.90	0.41
VMA*	16.78	16.73	15.33	14.94	15.63

Tests	Kraton Modified Conoco - 75 Blow Compaction			
Mean Marshall Stability in lbs.	3108.33	3800.33	3574.67	3372.00
Standard Dev. Marshall Stability	264.97	157.53	264.00	342.86
Mean Marshall Flow in 1/100 inch.	13.00	15.33	18.33	18.00
Standard Deviation Marshall Flow	1.73	0.58	2.08	1.73
Mean Bulk Specific Gravity	2.333	2.347	2.379	2.391
Standard Deviation Bulk Sp. Gr.	0.012	0.030	0.023	0.019
Unit Weight in Pcf.	145.58	146.45	148.45	149.20
Mean Rice Specific Gravity	2.434	2.439	2.449	2.424
Standard Deviation Rice Sp. Gr.	0.007	0.009	0.033	0.006
Mean Percent Air Voids	4.14	3.76	2.77	1.36
Standard Deviation % Air Voids	0.24	0.88	0.72	0.85
VMA*	16.84	15.89	15.20	15.22

Tests	Polybilt Modified Conoco - 75 Blow Compaction			
Mean Marshall Stability in lbs.	2758.33	2972.67	2903.33	2576.33
Standard Dev. Marshall Stability	378.59	360.58	266.84	167.31
Mean Marshall Flow in 1/100 inch.	13.67	13.33	15.33	16.33
Standard Deviation Marshall Flow	1.15	1.15	1.53	0.58
Mean Bulk Specific Gravity	2.345	2.400	2.416	2.399
Standard Deviation Bulk Sp. Gr.	0.004	0.010	0.005	0.016
Unit Weight in Pcf.	146.33	149.76	150.76	149.70
Mean Rice Specific Gravity	2.440	2.433	2.440	2.424
Standard Deviation Rice Sp. Gr.	0.049	0.035	0.021	0.015
Mean Percent Air Voids	4.06	2.78	2.54	1.37
Standard Deviation % Air Voids	1.26	1.14	0.84	0.51
VMA*	16.41	13.99	13.88	14.94

\* VMA values are based on assumed bulk specific gravity of aggregate = 2.651

1990 Asphalt

Table F3. Optimum Asphalt Content Based on Test Property Curves for  
3/4 inch Aggregates and Mineral Filler Mix with 50 Blow Compaction.

Asphalt	Unmodified Cenex	Kraton Modified Cenex	Polybilt Modified Cenex	Unmodified Conoco	Kraton Modified Conoco	Polybilt Modified Conoco
Max. Marshall Stability at Percent	4.50	4.50	4.50	4.50	4.50	4.50
Max. Unit Weight at Percent	5.00	5.00	5.50	5.50	4.50	5.00
4 Percent Air Voids at Percent	4.75	3.69	4.42	4.59	4.26	4.03
Average Optimum Asphalt Content	4.75	4.40	4.81	4.86	4.42	4.51

Properties of the Mix at Optimum Asphalt Content

Marshall Stability in lbs.	3021.00	3357.00	2993.75	3122.22	3578.26	2975.00
Marshall Flow in 1/100 Inch.	12.32	11.64	13.00	12.56	14.98	13.61
Unit Weight in gm/cc	2.396	2.390	2.398	2.385	2.351	2.397
Unit Weight in Pcf	149.51	149.14	149.64	148.82	146.70	149.57
Percent Air Voids in Percent	4.00	2.50	2.94	3.39	3.83	2.79

Table F4. Optimum Asphalt Content Based on Test Property Curve Data for  
3/4 inch Aggregates Mix with 50 Blow Compaction.\*

Asphalt	Unmodified	Kraton	Polybilt	Unmodified	Kraton	Polybilt
	Cenex	Modified	Modified	Conoco	Modified	Modified
		Cenex	Cenex		Conoco	Conoco
Max. Marshall Stability at Percent	6.00	5.50	6.00	5.50	6.00	5.50
Max. Unit Weight at Percent	6.00	6.50	6.00	5.00	5.50	5.50
4 Percent Air Voids at Percent	5.15	5.56	5.18	6.00	6.00	6.50
Average Optimum Asphalt Content	5.72	5.85	5.73	5.50	5.83	5.83

Properties of the Mix at Optimum Asphalt Content

Marshall Stability in lbs.	2386.00	2357.00	2465.00	2340.00	2632.00	2636.00
Marshall Flow in 1/100 Inch.	12.10	14.40	13.50	11.54	15.25	15.15
Unit Weight in gm/cc	2.388	2.365	2.386	2.387	2.379	2.387
Unit Weight in Pcf	149.01	147.58	148.89	148.95	148.45	148.95
Percent Air Voids in Percent	2.70	3.01	2.64	3.00	2.74	2.71

\* These values were obtained from phase I. 1989 - 1990 test results.

# Optimum Asphalt Content With & Without Mineral Filler for 3/4" Max. Size Agg.

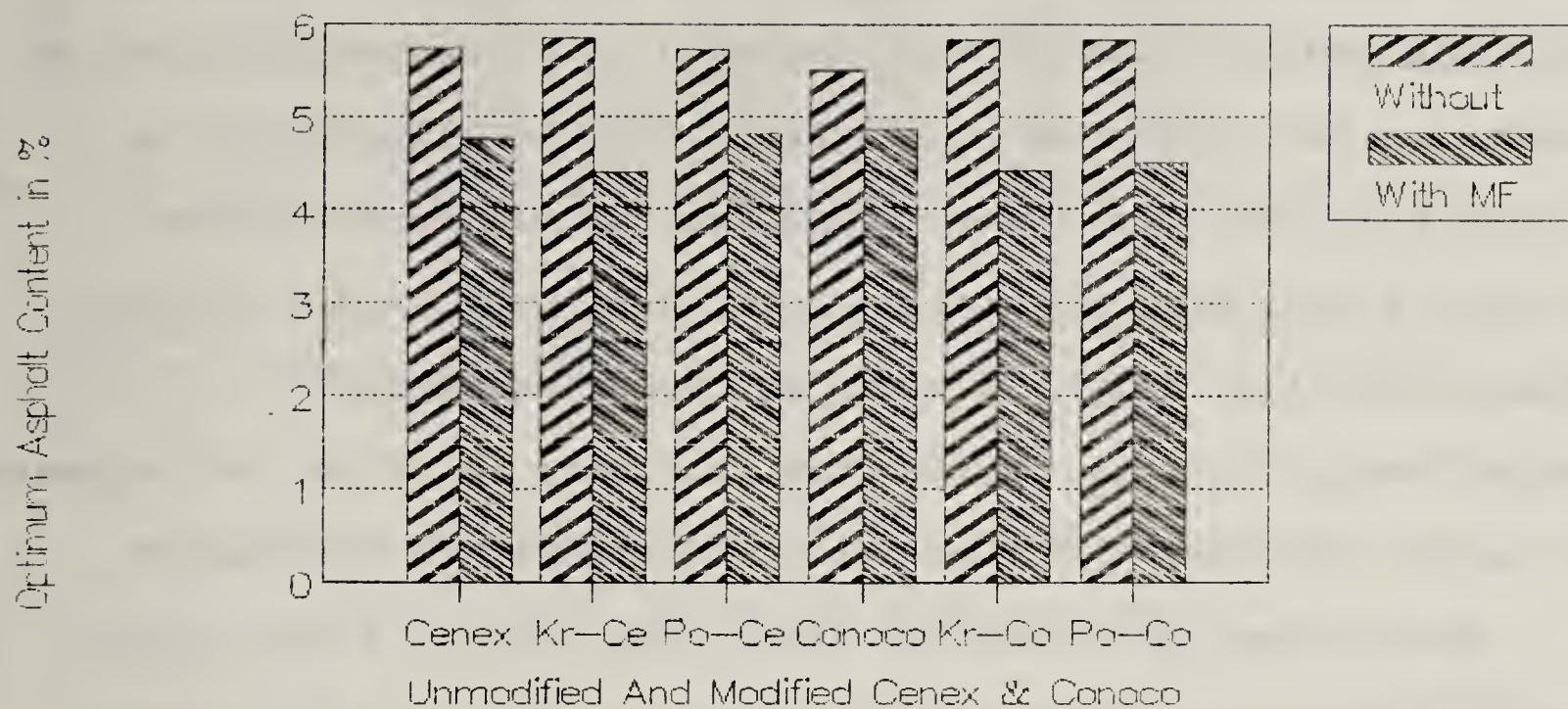


Figure F1. Optimum Asphalt Content for Conventional Aggregates with Mineral Filler.

## Marshall Stability - 3/4" Max. Size Agg With & Without Mineral Filler

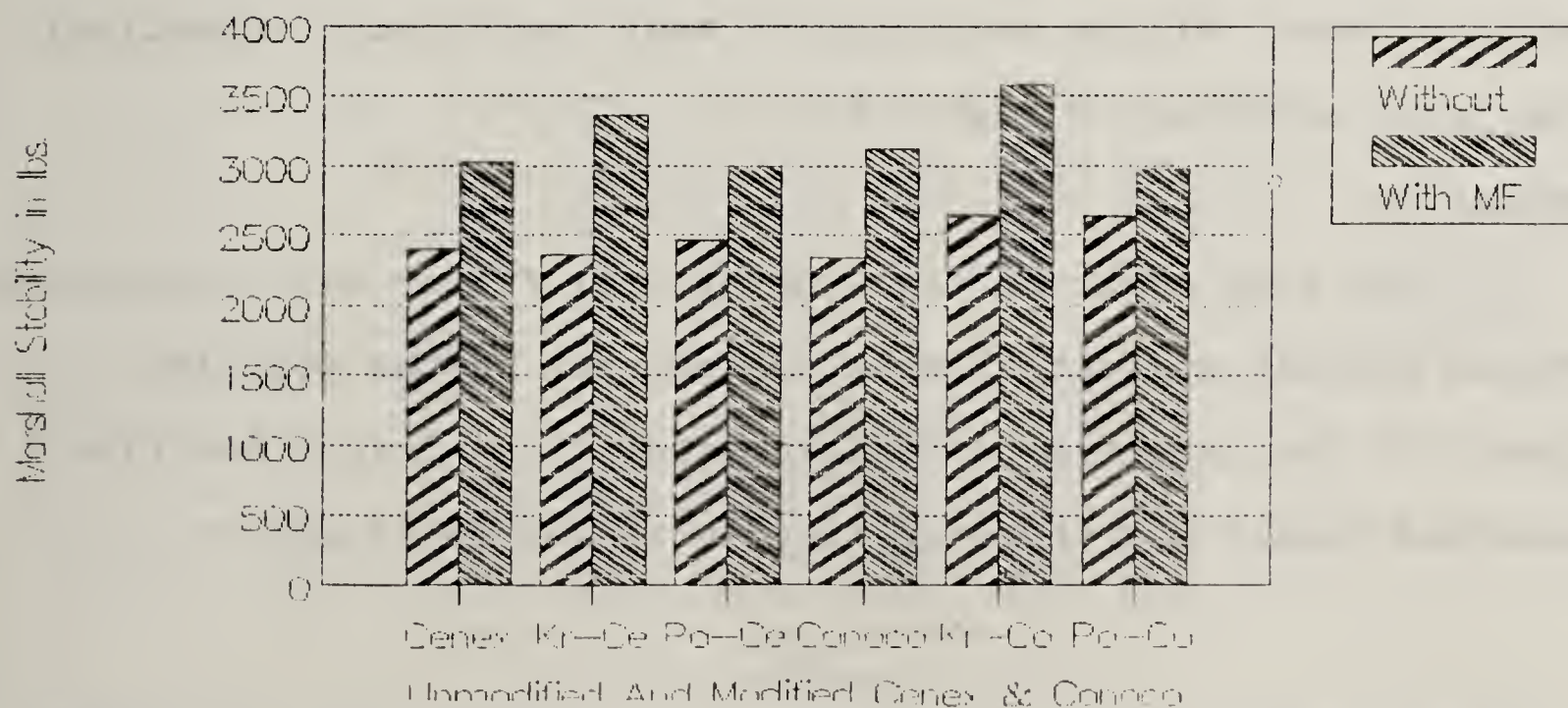


Figure F2. Stability for Conventional Aggregates Mix with and without Mineral Filler.

filler were improved by 21 and 13 percent respectively, whereas unmodified Cenex and Conoco were improved by 27 and 33 percent. This is illustrated in Figure F2.

The unit weight of all unmodified and modified Cenex and Polybilt modified Conoco were improved (i.e. became heavier) by about one half pound per cubic feet. This is illustrated in Figure F3. Also, the flows at optimum asphalt content with mineral filler were lowered by 2.76, 0.5, 0.27, and 1.54 for Kraton modified, Polybilt modified, Cenex and Conoco respectively. This is illustrated in Figure F4. With the decrease in asphalt content the flow value is expected to be lowered.

The percent air voids of mixes with mineral filler were higher than that of mixes without mineral filler in all cases except Kraton modified Cenex. This was expected with the lower asphalt content. However, the presence of mineral filler distorted the values to different degrees; for example, the percent air voids was increased by 1.3, 0.3, 0.39, 1.09, and 0.08 percent by reduction of asphalt content to different degrees, in spite of the presence of mineral filler for Cenex, Polybilt modified Cenex, Kraton and Polybilt modified Conoco respectively. This is illustrated in Figure F5.

### **Conclusion**

It has been observed that the mineral filler has reduced the optimum asphalt content by over one percent in the modified asphalt at the same time increasing stability. Kraton modified Cenex and Conoco had the stability increased by 42 and 36

Unit Weight—3/4-inch Max. Size Agg.  
With and Without Mineral Filler

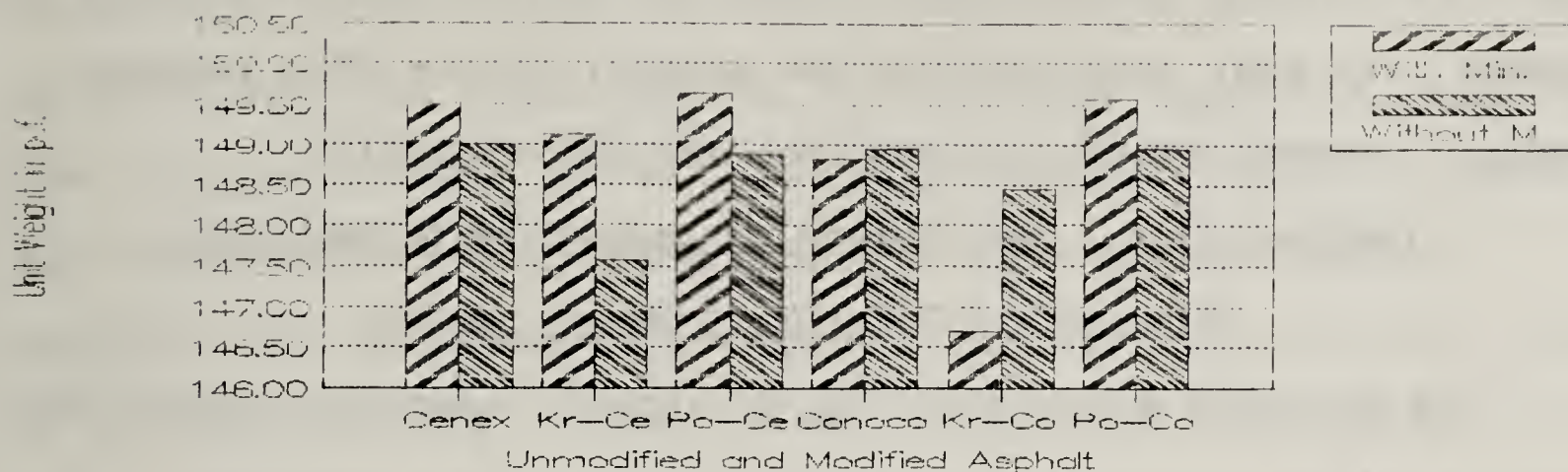


Figure F3. Unit Weight for Conventional Aggregates Mix with and without Mineral Filler.

Marshall Flow—3/4-inch Max. Size Agg.  
With and Without Mineral Filler

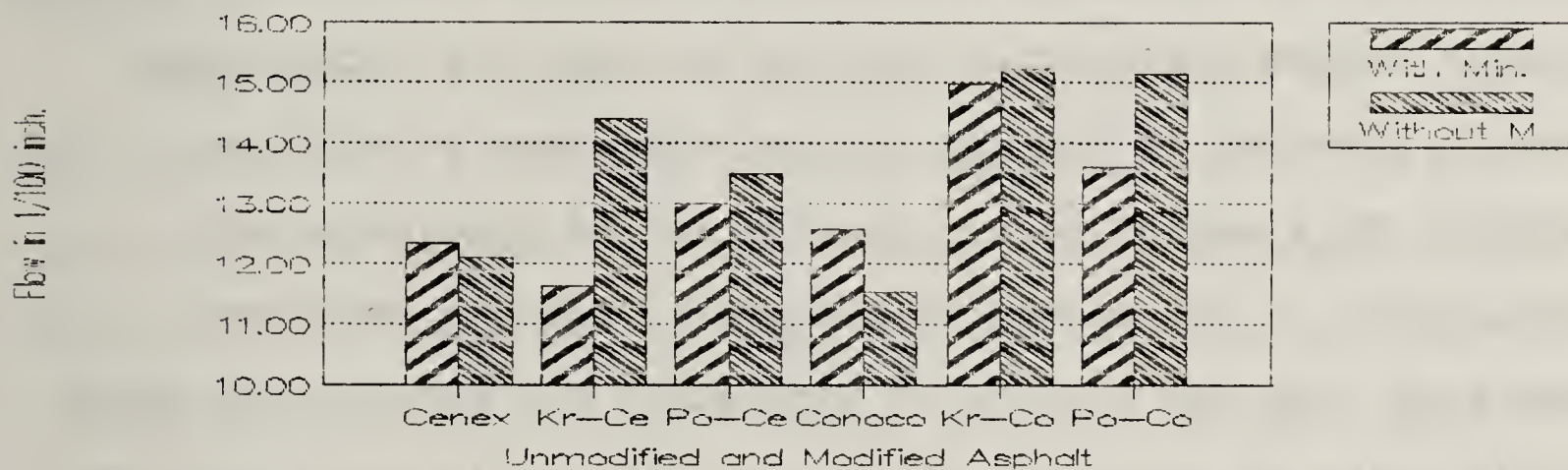


Figure F4. Flow for Conventional Aggregates Mix with and without Mineral Filler.

Air Voids—3/4-inch Max. Size Agg.  
With and Without Mineral Filler

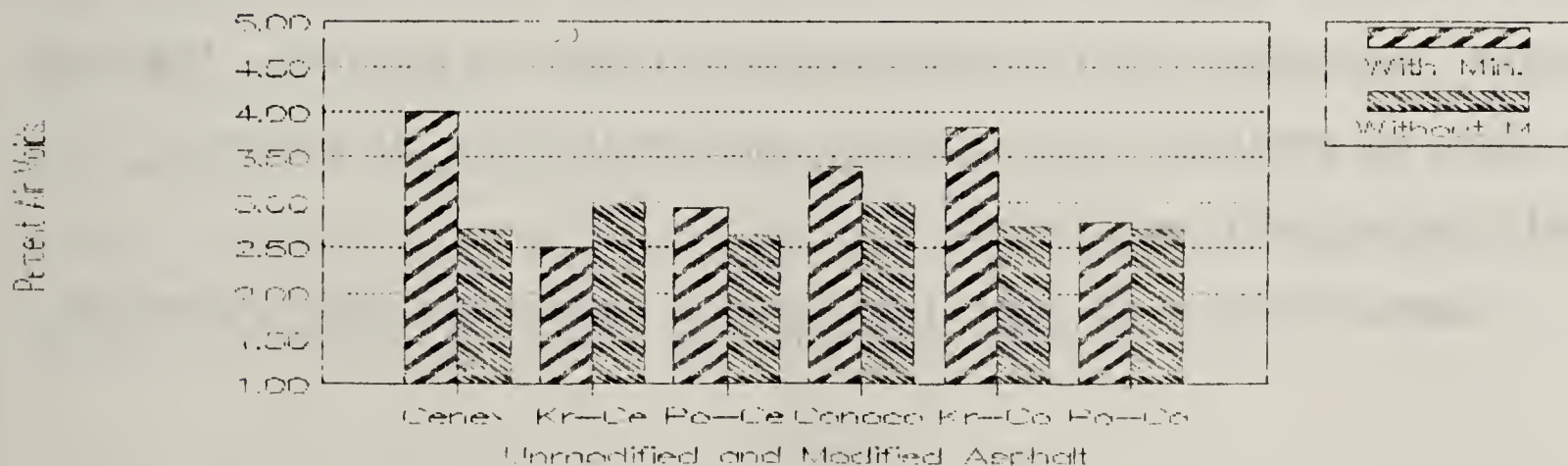


Figure F5. Air Voids for Conventional Aggregates Mix with and without Mineral Filler.

percent, while the optimum asphalt content was reduced by 1.45 and 1.41 percent respectively. Thus the Kraton modified Cenex and Conoco are most sensitive to the mineral filler. The reduced asphalt content results in obvious economic benefit.

#### Lottman Test - Resistance of Compacted Bituminous

##### Mixture to Moisture Induced Damage

The moisture susceptibility of asphalt concrete mixture is identified by performing laboratory tests on dry and wet accelerated conditioned specimens. Excessive moisture susceptibility is associated with low ratio of wet to dry mechanical properties. The standard method of test for "Resistance of Compacted Bituminous Mixtures to Moisture Induced Damage" AASHTO designation T283-85 was used for determining tensile strength of the dry and wet specimens of modified asphalt. This method covers preparation of specimens and measurement of the change of diametral tensile strength resulting from the effects of saturation and accelerated water conditioning of compacted bituminous mixture in the laboratory. The result may be used to predict long term stripping susceptibility of the bituminous mixtures, evaluating liquid antistripping additives, which are added to the asphalt cement or pulverulent solids, such as hydrated lime, which are added to the mineral aggregate.(10) In the present research project, the test is used to evaluate the moisture susceptibility of polymer modified asphalt concrete mix.

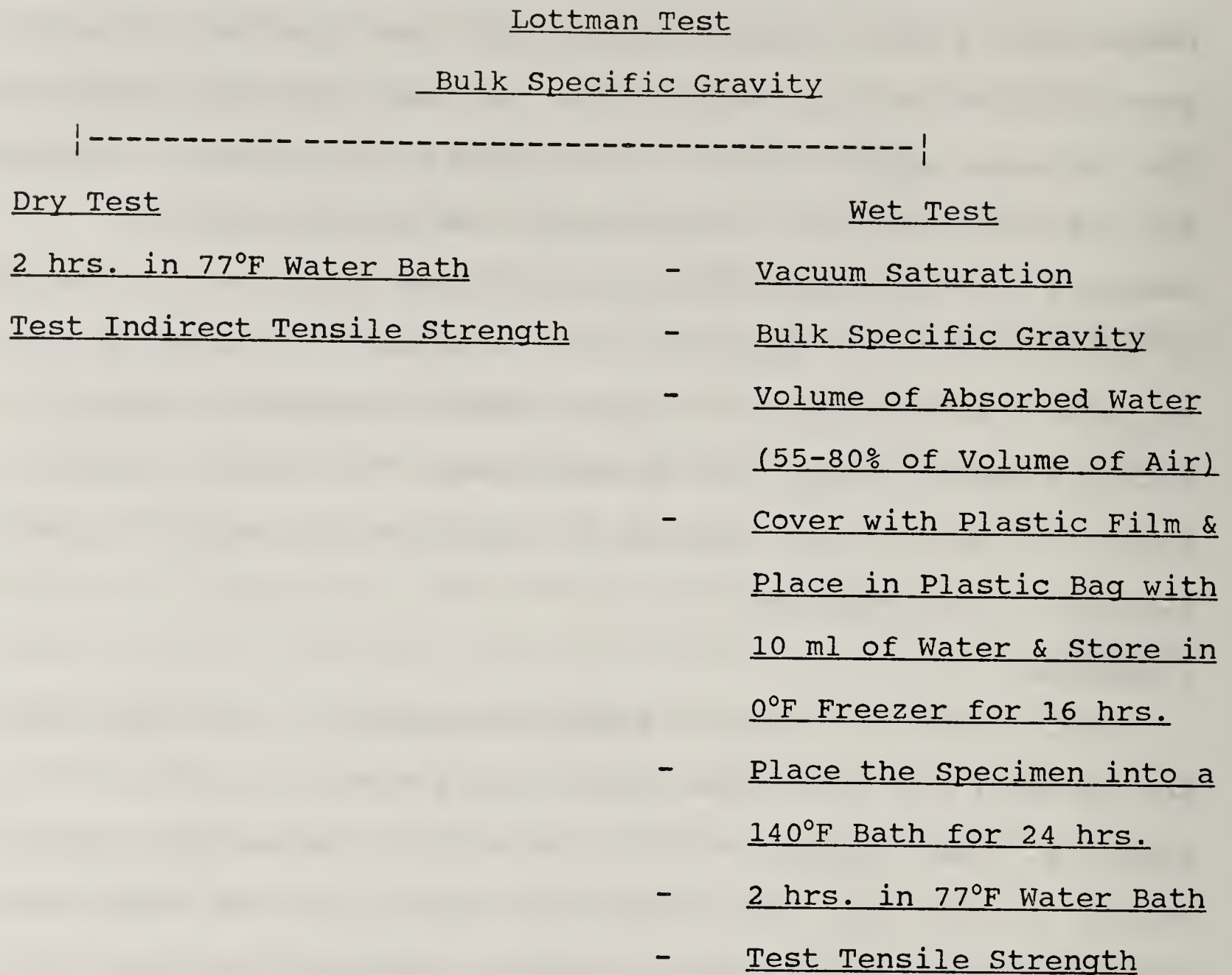
Large numbers of four inch molded specimens were prepared

for each of modified and unmodified asphalt under different compaction. A set of six specimens with 6 to 8 percent air voids were selected for each asphalt. For the same aggregate gradation, the optimum asphalt content, determined during Phase I, was used for the preparation of the specimens. The optimum asphalt contents for Cenex and Conoco were 5.72 and 5.5 percent by weight of mix respectively. Specimens with Cenex modified asphalts were prepared with 5.72 percent asphalt and Conoco modified asphalts with 5.5 percent asphalt by weight of mix. The rounded loading strip of 0.5-inch wide was used to determine the indirect tensile strength of the specimen.

### **Procedure**

Each batch of sample of aggregate-asphalt mix was mixed in the Marshall mix bench. The mixture was placed in a pan and cooled at room temperature for 2 hours. Then the samples were stored in 140°F oven for 16 hours for curing and then moved to a 275°F oven for 2 hours before compaction. The samples were compacted at different number of blows to achieve 6 to 8 percent air voids. After storing the samples for 72 to 96 hours at room temperature the samples were tested according to the flow chart as shown in Figure L1. One subset of three samples was tested for dry tensile strength and the other subset of three was tested for wet tensile strength. The maximum specific gravity was determined for each mix of modified and unmodified asphalt by Rice specific gravity AASHTO T209-82. Indirect tensile strength was determined using a constant 2-in/min deformation rate at 77°F.

Figure L1. Flow Chart for the Lottman Test.



### Results and Observations

The test results are shown in Table L1, L2, L3, L4, L5, and L6 for unmodified, Kraton and Polybilt modified, Cenex, and Conoco respectively. The specimen was fractured and results of the stripping was estimated. On 0 to 5 scale (1 for 50 - 60%, 2 for 60 - 70%, 3 for 70 - 80%, 4 for 80 - 90% and 5 for 90 - 100%.) are presented in the Tables. The visual stripping of wet specimens were lower compared to dry specimens in all cases. The

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Table L1. Lottman Test-Resistance of Compacted Bituminous Mixture to Moisture Induced Damage.

Asphalt - Unmodified Cenex

Percent Asphalt by Weight of Mix = 5.72

Mean Max. Specific Gravity (Rice Specific Gravity) = 2.444

Standard Deviation Max. Specific Gravity = .005

Compaction = 18 - 22 Blows

Tests	Conditioned Specimen			Dry Specimen		
	13	14	15	8	10	12
Sample I. D.	13	14	15	8	10	12
Diameter in inch.	4.00	4.00	4.00	4.00	4.00	4.00
Thickness in inch.	2 9/16	2 9/16	2 9/16	2.63	2.56	2.56
Dry Weight in Air in gm.	1208.00	1206.10	1209.10	1234.70	1207.90	1209.10
Surface Dry Weight in gm.	1213.30	1211.90	1214.80	1240.30	1213.20	1214.00
Weight in Water in gm.	683.00	679.90	681.20	698.40	682.20	686.20
Volume in c.c.	530.30	532.00	533.60	541.90	531.00	527.80
Bulk Specific Gravity.	2.278	2.267	2.266	2.278	2.275	2.291
Percent Air Voids.	6.79	7.24	7.29	6.77	6.92	6.27
Volume of Air Voids in c.c.	36.03	38.51	38.88	36.70	36.77	33.08
Load in lbs.				1425.00	1075.00	1275.00
Dry Tensile Strength in psi.				86.40	66.77	79.19
Average Dry Strength in psi.						77.45
Visual Stripping, 0-5 Scale				5	5	5

Saturation of Air Voids			
Surface Dry Weight in gm.	1231.80	1229.80	1232.10
Weight in Water in gm.	701.00	699.00	699.60
Volume in c.c.	530.80	530.50	532.50
Volume of Absorbed Water in c.c.	23.80	23.70	23.00
Percent Saturation	66.06	61.55	59.16
Percent Swell			

Conditioned 16 hrs. in 0F. and 24 hrs. in 140F Water.			
Thickness in Inch.	2.56	2.56	2.63
Surface Dry Weight in gm.	1228.90	1229.50	1232.50
Weight in Water in gm.	694.00	694.20	694.60
Volume in c.c.	534.90	535.30	537.90
Volume of Absorbed Water in c.c.	20.90	23.40	23.40
Percent Saturation	58.01	60.77	60.19
Percent Swell	0.87	0.62	0.81
Load in lbs.	925.00	875.00	825.00
Wet Tensile Strength in psi.	57.45	54.35	50.02
Average Wet Strength in psi.			53.94
Tensile Strength Ratio (TRS)			69.64
Visual Stripping, 0-5 Scale	3.00	3.00	3.00

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Table L2. Lottman Test- Resistance of Compacted Bituminous Mixture to Moisture Induced Damage.

Asphalt - Kraton Modified Cenex

Percent Asphalt by Weight of Mix = 5.72

Mean Max. Specific Gravity (Rice Specific Gravity) = 2.436

Standard Deviation Max. Specific Gravity = .007

Compaction = 15 - 20 Bolws

Tests	Conditioned Specimen			Dry Specimen			
	13	14	15	3	5	6	
Sample I. D.	13	14	15	3	5	6	
Diameter in inch	4.00	4.00	4.00	4.00	4.00	4.00	
Thickness in inch				2.56	2.56	2.50	
Dry Weight in Air in gm.	1196.10	1197.80	1208.80	1201.00	1201.00	1188.00	
Surface Dry Weight in gm.	1203.70	1204.60	1217.40	1207.70	1206.80	1192.20	
Weight in Water in gm.	678.70	680.30	687.80	681.30	682.40	672.40	
Volume in c.c.	525.00	524.30	529.60	526.40	524.40	519.80	
Bulk Specific Gravity	2.278	2.285	2.282	2.282	2.290	2.285	
Percent Air Voids	6.47	6.22	6.30	6.34	5.98	6.18	
Volume of Air Voids in c.c.	33.99	32.59	33.38	33.38	31.38	32.12	
Load in lbs.				1725.00	1475.00	1500.00	
Dry Tensile Strength in psi.				107.14	91.61	95.49	
Average Dry Strength in psi.							98.08
Visual Stripping, 0-5 Scale				5	5	5	5
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Saturation of Air Voids							
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Surface Dry Weight in gm.	1218.20	1222.00	1229.40				
Weight in Water in gm.	696.90	699.10	702.40				
Volume in c.c.	522.60	522.90	527.00				
Volume of Absorbed Water in c.c.	22.10	24.20	20.60				
Percent Saturation	65.02	74.25	61.72				
Percent Swell							
Conditioned 16 hrs. in OF. and 24 hrs. in 140F Water.							
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Thickness in Inch.	2.56	2.56	2.56				
Surface Dry Weight in gm.	1219.90	1223.20	1231.10				
Weight in Water in gm.	693.00	695.00	699.70				
Volume in c.c.	526.90	528.20	531.40				
Volume of Absorbed Water in c.c.	23.80	25.40	22.30				
Percent Saturation	70.02	77.93	66.81				
Percent Swell	0.36	0.74	0.34				
Load in lbs.	1150.00	1300.00	1350.00				
Wet Tensile Strength in psi.	71.43	80.74	83.85				
Average Wet Strength in psi.							78.67
Tensile Strength Ratio (TRS)							80.21
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Visual Stripping, 0-5 Scale	3.00	3.00	3.00				3
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Table L3. Lottman Test - Resistance of Compacted Bituminous Mixture to Moisture Induced Damage.

Asphalt - Polybilt Modified Cenex

Percent Asphalt by Weight of Mix = 5.72

Mean Max. Specific Gravity (Rice Specific Gravity) = 2.444

Standard Deviation Max. Specific Gravity = .001

Compaction = 19 - 21 Blows

Tests	Conditioned Specimen			Dry Specimen		
	8	9	10	3	4	5
Sample I. D.	8	9	10	3	4	5
Diameter in inch.	4.00	4.00	4.00	4.00	4.00	4.00
Thickness in inch.				2.56	2.56	2.56
Dry Weight in Air in gm.	1208.80	1212.90	1212.40	1202.60	1211.40	1199.30
Surface Dry Weight in gm.	1214.30	1218.80	1217.50	1209.70	1216.80	1204.60
Weight in Water in gm.	685.40	688.50	687.80	684.10	686.00	676.40
Volume in c.c.	528.90	530.30	529.70	525.60	530.80	528.20
Bulk Specific Gravity.	2.285	2.287	2.289	2.288	2.282	2.271
Percent Air Voids.	6.49	6.42	6.35	6.38	6.62	7.10
Volume of Air Voids in c.c.	34.30	34.02	33.63	33.54	35.14	37.49
Load in lbs.				1700.00	1500.00	1725.00
Dry Tensile Strength in psi.				105.64	93.16	107.14
Average Dry Strength in psi.						101.98
Visual Stripping, 0-5 Scale				5	5	5
-----						
Saturation of Air Voids						
-----						
Surface Dry Weight in gm.	1228.40	1231.90	1232.70			
Weight in Water in gm.	701.00	701.50	702.50			
Volume in c.c.	527.40	530.40	530.20			
Volume of Absorbed Water in c.c.	19.60	19.00	20.30			
Percent Saturation	57.14	55.84	60.37			
Percent Swell	-0.28	0.02	0.09			
Conditioned 16 hrs. in 0F. and 24 hrs. in 140F Water.						
-----						
Thickness in Inch.	2.56	2.56	2.56			
Surface Dry Weight in gm.	1228.70	1232.20	1232.50			
Weight in Water in gm.	698.70	699.60	701.50			
Volume in c.c.	530.00	532.60	531.00			
Volume of Absorbed Water in c.c.	19.90	19.30	20.10			
Percent Saturation	58.02	56.73	59.77			
Percent Swell	0.21	0.43	0.25			
Load in lbs.	1325.00	1350.00	1300.00			
Wet Tensile Strength in psi.	82.29	83.85	80.74			
Average Wet Strength in psi.						82.29
Tensile Strength Ratio (TRS)						80.70
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Visual Stripping, 0-5 Scale	4	4	4			4
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Table L4. Lottman Test - Resistance of Compacted Bituminous Mixture to Moisture Induced Damage.

Asphalt - Unmodified Conoco

Percent Asphalt by Weight of Mix = 5.5

Mean Max. Specific Gravity (Rice Specific Gravity) = 2.444

Standard Deviation Max. Specific Gravity = .002

Compaction = 17 - 19 Bolws

Tests	Conditioned Specimen			Dry Specimen		
	10	11	14	5	15	12
Sample I. D.	4.00	4.00	4.00	4.00	4.00	4.00
Diameter in inch.	4.00	4.00	4.00	4.00	4.00	4.00
Thickness in inch.				2.56	2.56	2.50
Dry Weight in Air in gm.	1214.20	1207.20	1214.60	1204.50	1209.00	1191.50
Surface Dry Weight in gm.	1221.90	1216.90	1221.90	1209.50	1213.10	1199.20
Weight in Water in gm.	688.00	689.10	692.80	684.00	685.20	678.10
Volume in c.c.	533.90	527.80	529.10	525.50	527.90	521.10
Bulk Specific Gravity.	2.274	2.287	2.296	2.292	2.290	2.287
Percent Air Voids.	6.95	6.41	6.07	6.22	6.29	6.44
Volume of Air Voids in c.c.	37.09	33.86	32.13	32.66	33.22	33.58
Load in lbs.				1450.00	1300.00	1225.00
Dry Tensile Strength in psi.				90.10	80.74	77.99
Average Dry Strength in psi.						82.94
Visual Stripping, 0-5 Scale				5	5	5

Saturation of Air Voids

Surface Dry Weight in gm.	1236.90	1228.20	1233.80
Weight in Water in gm.	701.10	695.80	701.60
Volume in c.c.	535.80	532.40	532.20
Volume of Absorbed Water in c.c.	22.70	21.00	19.20
Percent Saturation	61.20	62.03	59.76
Percent Swell	0.36	0.87	0.59

Conditioned 16 hrs. in OF. and 24 hrs. in 140F Water.

Thickness in Inch.	2.63	2.56	2.56
Surface Dry Weight in gm.	1237.10	1225.80	1234.30
Weight in Water in gm.	698.80	692.30	699.10
Volume in c.c.	538.30	533.50	535.20
Volume of Absorbed Water in c.c.	22.90	18.60	19.70
Percent Saturation	61.74	54.94	61.32
Percent Swell	0.82	1.08	1.15
Load in lbs.	1150.00	1200.00	1250.00
Wet Tensile Strength in psi.	69.72	74.53	77.64
Average Wet Strength in psi.			73.96
Tensile Strength Ratio (TRS)			89.17
Visual Stripping, 0-5 Scale	4	4	4

Table L5. Lottman Test - Resistance of Compacted Bituminous Mixture to Moisture Induced Damage.

Asphalt - Kraton Modified Conoco

Percent Asphalt by Weight of Mix = 5.5

Mean Max. Specific Gravity (Rice Specific Gravity) = 2.430

Standard Deviation Max. Specific Gravity = .003

Compaction = 22 - 24 Bolws

Tests	Conditioned Specimen			Dry Specimen		
	10	11	12	4	5	8
Sample I. D.	4.00	4.00	4.00	4.00	4.00	4.00
Diameter in inch.	4.00	4.00	4.00	4.00	4.00	4.00
Thickness in inch.				2.63	2.56	2.56
Dry Weight in Air in gm.	1207.70	1207.40	1208.20	1205.40	1204.70	1207.10
Surface Dry Weight in gm.	1215.30	1211.50	1213.90	1213.30	1211.00	1216.00
Weight in Water in gm.	681.90	682.80	684.70	677.40	677.70	686.20
Volume in c.c.	533.40	528.70	529.20	535.90	533.30	529.80
Bulk Specific Gravity.	2.264	2.284	2.283	2.249	2.259	2.278
Percent Air Voids.	6.82	6.02	6.05	7.44	7.04	6.24
Volume of Air Voids in c.c.	36.40	31.83	32.00	39.85	37.54	33.05
Load in lbs.				1625.00	2100.00	1650.00
Dry Tensile Strength in psi.				98.57	130.43	102.48
Average Dry Strength in psi.						110.49
Visual Stripping, 0-5 Scale				5	5	5
-----						
Saturation of Air Voids						
-----						
Surface Dry Weight in gm.	1228.70	1227.60	1228.90			
Weight in Water in gm.	692.50	696.90	697.50			
Volume in c.c.	536.20	530.70	531.40			
Volume of Absorbed Water in c.c.	21.00	20.20	20.70			
Percent Saturation	57.69	63.47	64.69			
Percent Swell	0.52	0.38	0.42			
Conditioned 16 hrs. in 0F. and 24 hrs. in 140F Water.						
-----						
Thickness in Inch.	2.63	2.56	2.56			
Surface Dry Weight in gm.	1228.10	1227.50	1227.40			
Weight in Water in gm.	689.80	694.80	693.60			
Volume in c.c.	538.30	532.70	533.80			
Volume of Absorbed Water in c.c.	20.40	20.10	19.20			
Percent Saturation	56.04	63.15	60.00			
Percent Swell	0.92	0.76	0.87			
Load in lbs.	1350.00	1350.00	1400.00			
Wet Tensile Strength in psi.	81.85	83.85	86.95			
Average Wet Strength in psi.						84.22
Tensile Strength Ratio (TRS)						76.22
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Visual Stripping, 0-5 Scale	4	4	5			4
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Table L6. Lottman Test - Resistance of Compacted Bituminous Mixture to Moisture Induced Damage.

Asphalt - Polybilt Modified Conoco

Percent Asphalt by Weight of Mix = 5.5

Mean Max. Specific Gravity (Rice Specific Gravity) = 2.450

Standard Deviation Max. Specific Gravity = .003

Compaction = 19 - 20 Blows

Tests	Conditioned Specimen			Dry Specimen			
	9	10	11	5	7	8	
Sample I. D.	4.00	4.00	4.00	4.00	4.00	4.00	
Diameter in inch.	4.00	4.00	4.00	4.00	4.00	4.00	
Thickness in inch.				2.56	2.56	2.56	
Dry Weight in Air in gm.	1204.20	1203.10	1198.60	1199.20	1205.20	1204.30	
Surface Dry Weight in gm.	1211.00	1209.00	1204.50	1207.40	1212.10	1212.90	
Weight in Water in gm.	684.60	679.10	676.80	677.10	679.10	680.00	
Volume in c.c.	526.40	529.90	527.70	530.30	533.00	532.90	
Bulk Specific Gravity.	2.288	2.270	2.271	2.261	2.261	2.260	
Percent Air Voids.	6.63	7.33	7.29	7.70	7.71	7.76	
Volume of Air Voids in c.c.	34.89	38.84	38.48	40.83	41.08	41.35	
Load in lbs.				1450.00	1600.00	1675.00	
Dry Tensile Strength in psi.				90.10	99.37	104.03	
Average Dry Strength in psi.							97.84
Visual Stripping, 0-5 Scale				5	5	5	5
-----							
Saturation of Air Voids							
-----							
Surface Dry Weight in gm.	1225.50	1227.70	1222.40				
Weight in Water in gm.	695.40	692.30	694.60				
Volume in c.c.	530.10	535.40	527.80				
Volume of Absorbed Water in c.c.	21.30	24.60	23.80				
Percent Saturation	61.05	63.34	61.86				
Percent Swell	0.70	1.04	0.02				
Conditioned 16 hrs. in OF. and 24 hrs. in 140F Water.							
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Thickness in Inch.	2.63	2.56	2.56				
Surface Dry Weight in gm.	1231.00	1228.80	1223.20				
Weight in Water in gm.	694.20	698.40	693.40				
Volume in c.c.	536.80	530.40	529.80				
Volume of Absorbed Water in c.c.	26.80	25.70	24.60				
Percent Saturation	76.81	66.17	63.94				
Percent Swell	1.98	0.09	0.40				
Load in lbs.	1250.00	1375.00	1250.00				
Wet Tensile Strength in psi.	75.79	85.40	77.64				
Average Wet Strength in psi.							79.61
Tensile Strength Ratio (TRS)							81.37
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Visual Stripping, 0-5 Scale	4	4	4				4
-----							

percent swell are also shown in above tables.

The dry and wet tensile strength and tensile strength ratio are shown in Table L7. The dry tensile strengths of modified asphalt mixes were higher compared to that of unmodified asphalt mix. The dry tensile strength of unmodified Cenex and Conoco were 77.48 psi, and 82.94 psi respectively, whereas that of Kraton and Polybilt modified Cenex, and Conoco were 98.08, 101.98, 110.49, and 97.84 respectively. This shows that the dry tensile strength was improved by modification.

Similarly, the wet tensile strengths of unmodified Cenex and Conoco were only 53.94 and 73.96, whereas those of Kraton and Polybilt modified Cenex, and Conoco were 78.67, 82.29, 84.22, and 79.61 respectively. The improvement is highest in the case of Polybilt modified Cenex. The relative improvement of dry and wet tensile strength is demonstrated in Figures L2, and L3.

Moisture susceptibility is associated with a decrease in the wet tensile strength. It is observed that the wet tensile strength is lower than the dry. But the decrease in the tensile strength ratio (TSR) differs to varying degrees. In the case of unmodified Cenex, the tensile strength ratio is 69.64. The tensile strength ratio for Kraton and Polybilt modified Cenex were 80.2 and 82.29 respectively, which are higher by 10 percent compared to unmodified Cenex. But in the case of Conoco, Kraton, Polybilt, and unmodified Conoco the tensile strength ratios are 89.17, 76.22 and 81.37 respectively. Although the wet tensile strength of modified Conoco was improved compared to unmodified

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Table L7. Dry and Wet Tensile Strengths and Tensile Strength Ratio of the Unmodified and Modified Asphalt.

Asphalt	Cenex	Kraton Modified Cenex	Polybilt Modified Cenex	Conoco	Kraton Modified Conoco	Polybilt Modified Conoco
Dry Tensile Strength in psi	77.45	98.08	101.98	82.94	110.49	97.84
Wet Tensile Strength in psi	53.94	78.67	82.29	73.96	84.22	79.61
Tensile Strength Ratio (TSR) in %	69.64	80.21	80.7	89.17	76.22	82.37
Dry Visual Stripping (0-5 Scale)	5	5	5	5	5	5
Wet Visual Stripping (0-5 Scale)	3	3	4	4	4	4

Asphalt Test Results.

After TFOT Penetration at 77°F in dmm.	91.78	71.78	64.33	93.67	71.88	60.58
Stability in lb. on 4-inch Specimens.*	2386	2357	2465	2340	2632	2636

\* Stability values were obtained from phase I. 1989-90 results.

# Lottman Test—Dry & Wet Tensile Strength for Modified & Unmodified Asphalt

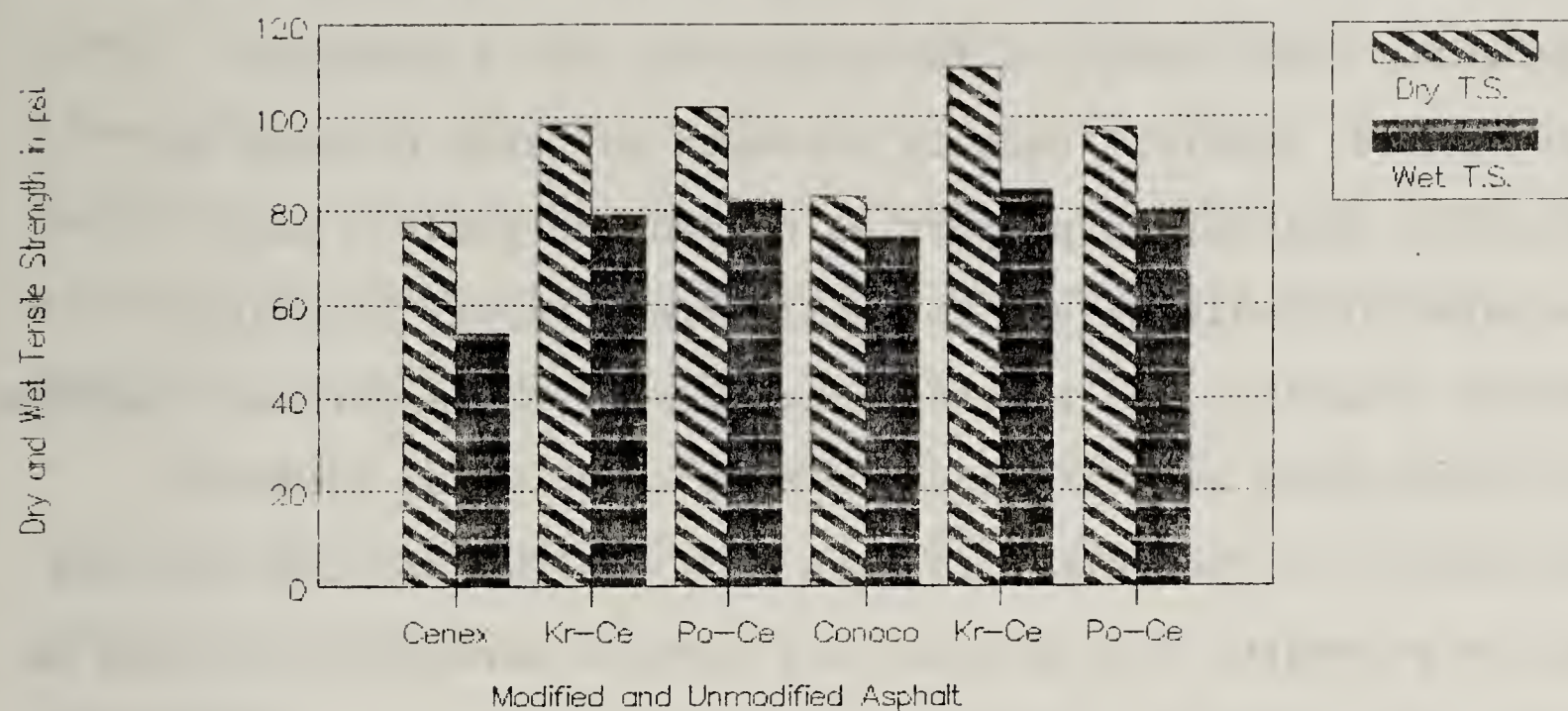


Figure L2. Lottman Test-Dry and Wet Tensile Strength for Unmodified and Modified Asphalt.

# Lottman Test – Tensile Strength Ratio for Modified & Unmodified Asphalt

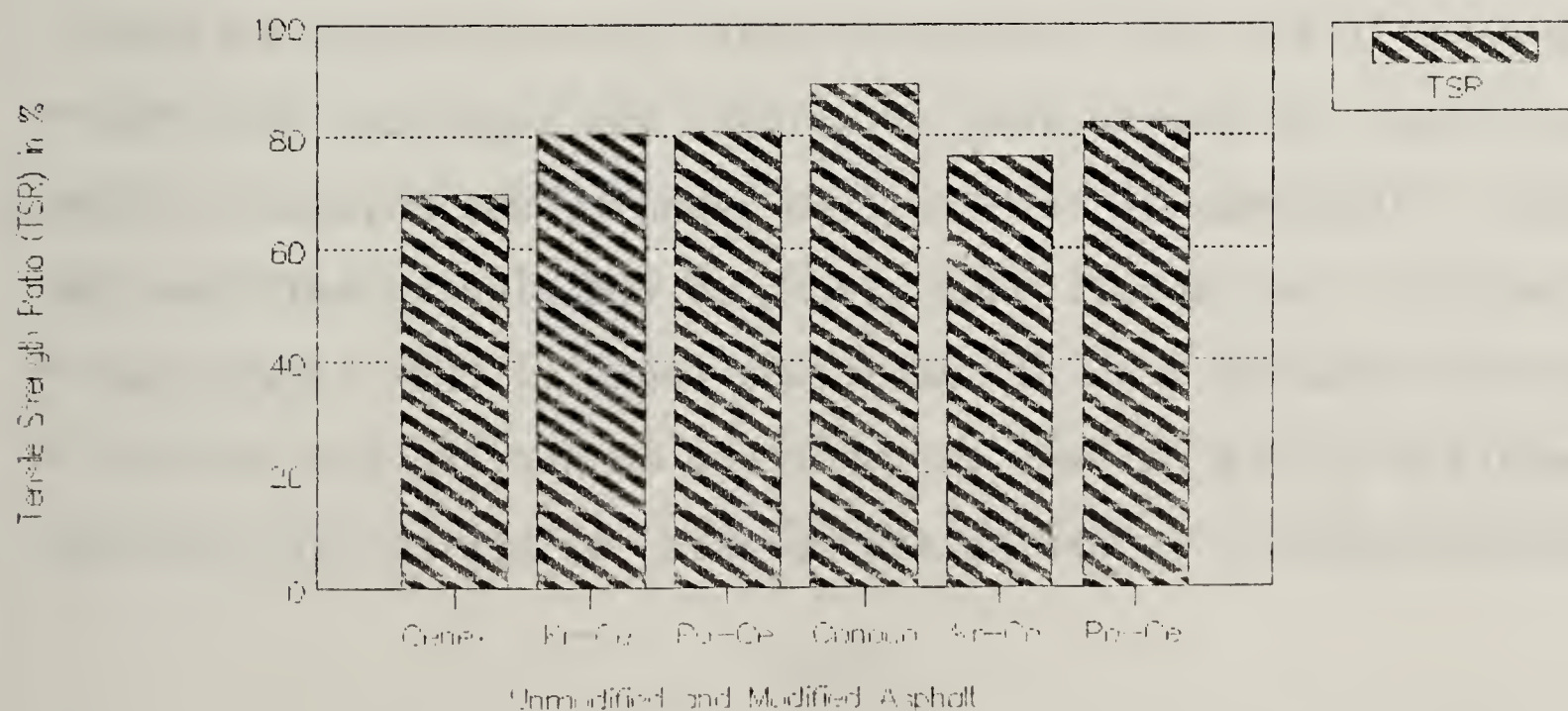


Figure L3. Tensile Strength Ratio for Unmodified and Modified Asphalt.

Conoco, the improvement was not to the same degree as that of the dry tensile strength. Thus the tensile strength ratios were lower compared to unmodified Conoco. This is demonstrated in Figure L3.

The indirect tensile test on asphalt concrete mix is a frequently used procedure for assessing likely pavement performance. Indirect tensile strength may also be used to determine engineering properties needed for elastic and viscoelastic analysis and for evaluating thermal cracking, fatigue cracking, and potential problems with tenderness. Garrick and Biskur have demonstrated a strong correlation between penetration of the Thin Film Oven Test residue and indirect dry tensile strength. The indirect dry tensile strength increases as penetration decreases. (11)

A similar effect has been observed in case of unmodified and modified Cenex. In the case of Conoco, indirect dry tensile strength of Polybilt modified Conoco and Kraton modified Conoco did not follow the direct relation with the decrease in penetration.

When the Kraton and Polybilt polymer modified asphalts were dissolved in the THF (Tetrahydrofuran), and subjected to the centrifuge, the particulate of polymer was separated out. The polymer, dispersed in the modified asphalt, was physically bonded to asphalt. The asphalt composition of modified asphalt was the basically same as that of unmodified asphalt. That is why the separation of the polymer was observed on heating the stored modified asphalt, requiring redispersing by mixing. In modified

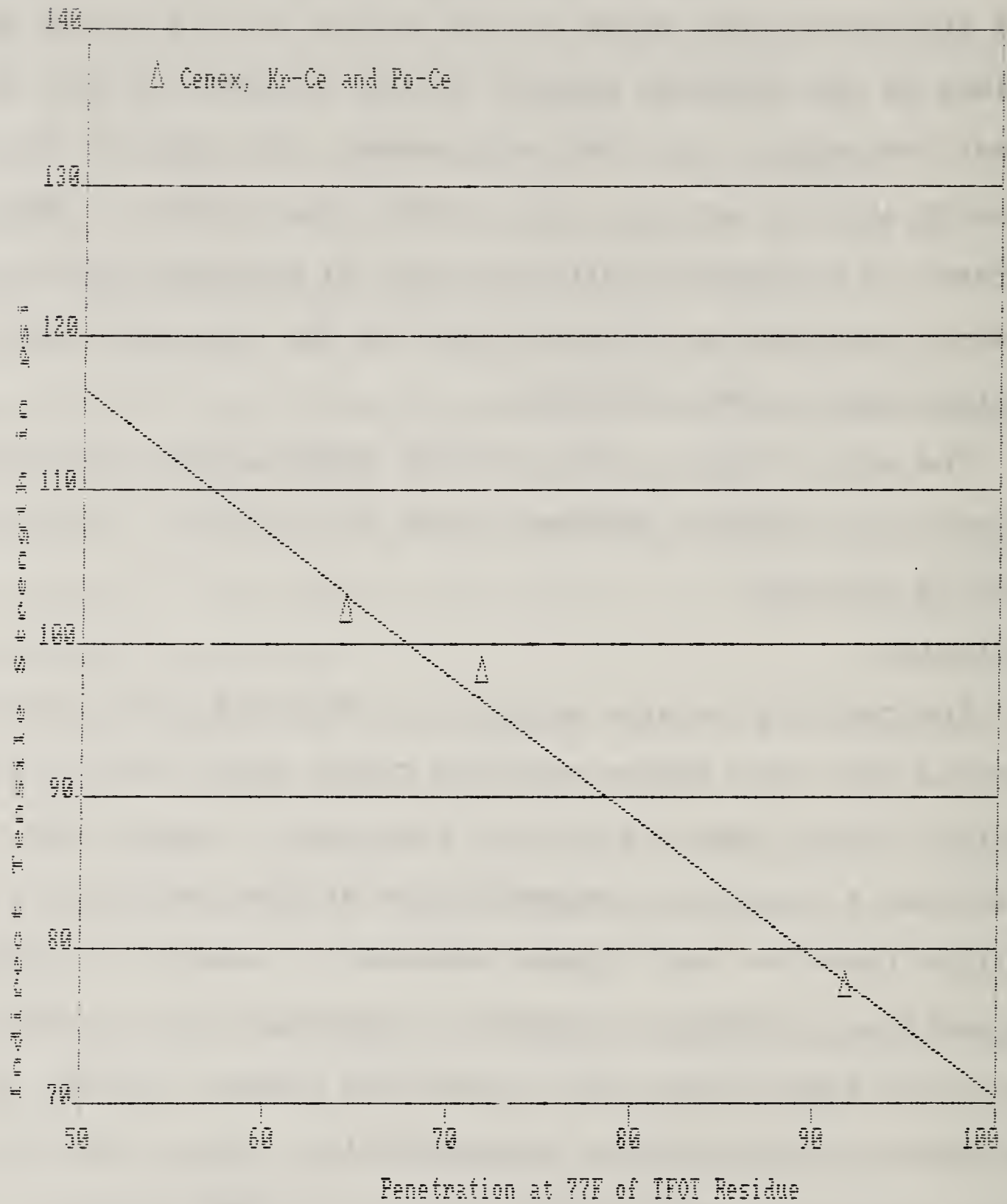
asphalt the polymer chain is stretched out in the mass of asphalt, resulting in the improvement in physical properties. Thus the penetration value at 77°F of the Thin Film Oven Test residue of the modified asphalt is low compared to that of unmodified asphalt. For the same reason, the indirect dry tensile strength is also improved. The linear relationship of the decrease in penetration with increase in indirect dry tensile strength is shown in Figures L4 and L5 for Cenex and Conoco modified asphalt respectively.

The modification of the asphalt improved the dry tensile strength to different degrees: Kr-Ce 27, Po-Ce 32, Kr-Co 33, and Po-Co 18 percent.

### Conclusion

Indirect dry tensile strength of Polybilt modified Cenex was improved more than Kraton modified Cenex, while that of Kraton modified Conoco improved most in the case of Conoco. The resistance to moisture susceptibility of the Kraton and Polybilt modified Cenex was much higher compared to unmodified Cenex, whereas the resistance of moisture susceptibility of unmodified Conoco was better than that of modified Conoco. In view of the resistance to the moisture susceptibility, Cenex would be a better choice for modification first by Polybilt then by Kraton. There seems to exist a weak relationship between the stability and tensile strength of the modified and unmodified asphalt. The stability of Kraton modified Cenex was improved by 6 percent. Indirect tensile strength of Kraton modified Cenex was improved

# Dry Tensile Strength - Penetration after TFOT



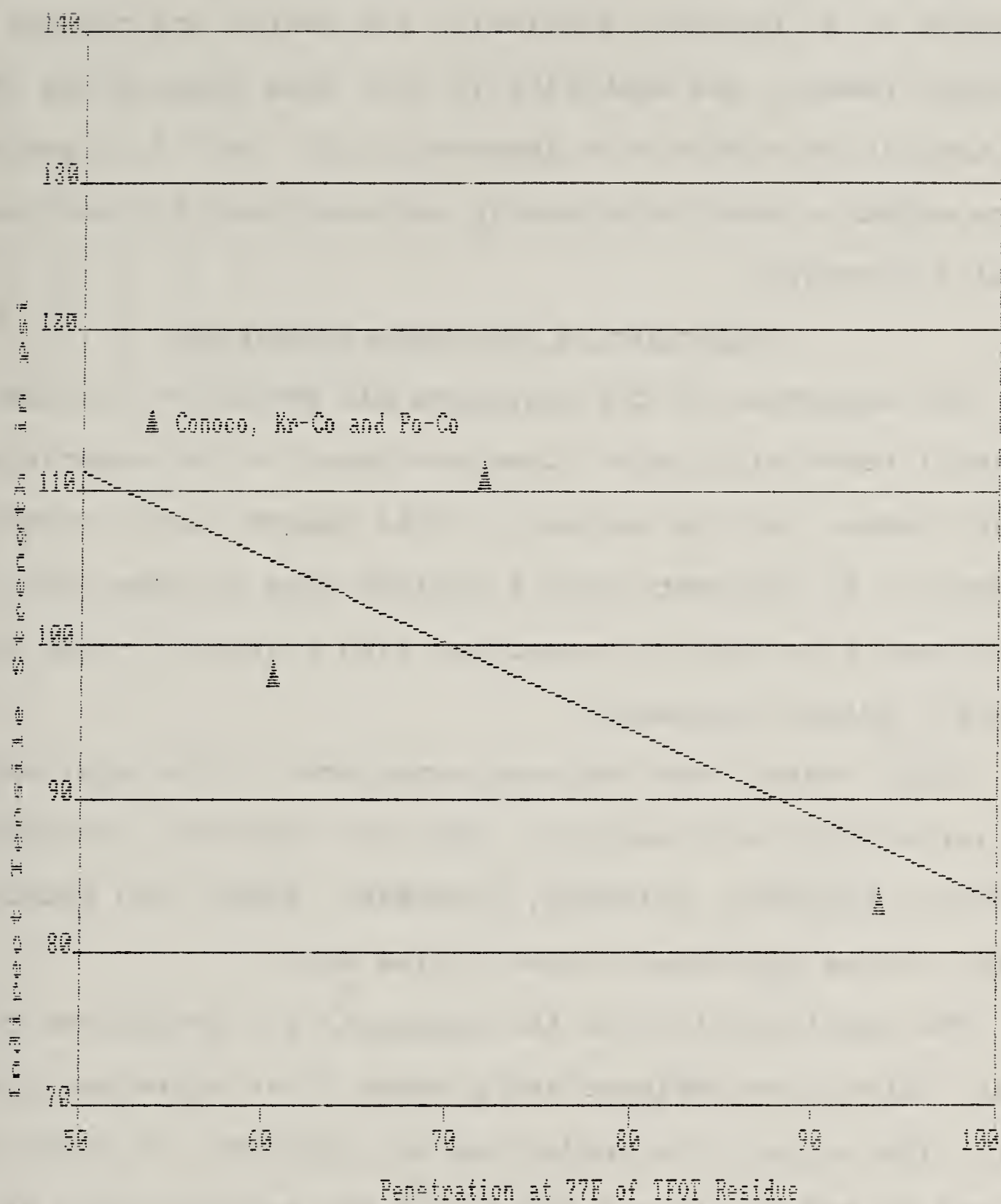
THE REGRESSION POLYNOMIAL OF LINE 1 -

$$(1.626E+02) + (-9.223E-01)*X$$

THE VARIANCE - 1.580E+00

Figure L4. Linear Relationship of ATFOT Penetration and Indirect Dry Tensile Strength for Cenex.

# Dry Tensile Strength - Penetration of TFOT Residue



REGRESSION POLYNOMIAL OF LINE 1 -

$$(1.392E+02) + (-5.583E-01)*X$$

THE VARIANCE - 6.784E+01

Figure L5. Linear Relationship of ATFOT Penetration and Indirect Dry Tensile Strength for Conoco.

by 27 percent. For Polybilt modified Cenex, the stability was improved by 3.31 percent but the dry tensile strength was improved by 32 percent. Similarly, for Kraton and polybilt modified Conoco, the stability in both were improved by 12% while dry tensile strengths were improved 33.22 and 17.96 percent. There exists a weak relationship between stability and indirect tensile strength.

### Selection of Aggregate Gradation

The selection of the aggregate mix gradation for the first Marshall tests with large stone was based on the experience in other states. For the purpose of this report "large stone" is defined as an aggregate with a maximum size of more than 1 inch, which cannot be used in connection with standard 4-inch diameter Marshall molded specimens.

Eight states have had some experience in the application of the large stone mix design.(4) They are Arkansas, California, Colorado, Kentucky, Oklahoma, Tennessee, Texas, and Wyoming. None of the states have used "stone filled mix".

The specifications of the aggregate mix gradations of all eight states were reviewed and plotted in an aggregate gradation chart. The comparative gradations of aggregate are shown in Figures G1 and G2. It was found that the specification of the state of California represents the median value specification. Moreover, the construction of the pavement with the gradation experienced no problems and the specified density was achieved. Incidentally, the gradation was found to be close to the one used

BY 12-21-11  
DATE 11-11-11

# GRADATION CURVE

SIZE ANALYSIS

NUMBER OF MESH US STANDARD

- Wyoming (1 1/4")
- Montana (1")
- Arkansas (3", 2")
- Oklahoma (1 1/2")
- Colorado (1 1/2")
- California (1 1/2")

[Symbol] Wyoming (1 1/4")  
 [Symbol] Montana (1")  
 [Symbol] Arkansas (3", 2")  
 [Symbol] Oklahoma (1 1/2")  
 [Symbol] Colorado (1 1/2")  
 [Symbol] California (1 1/2")

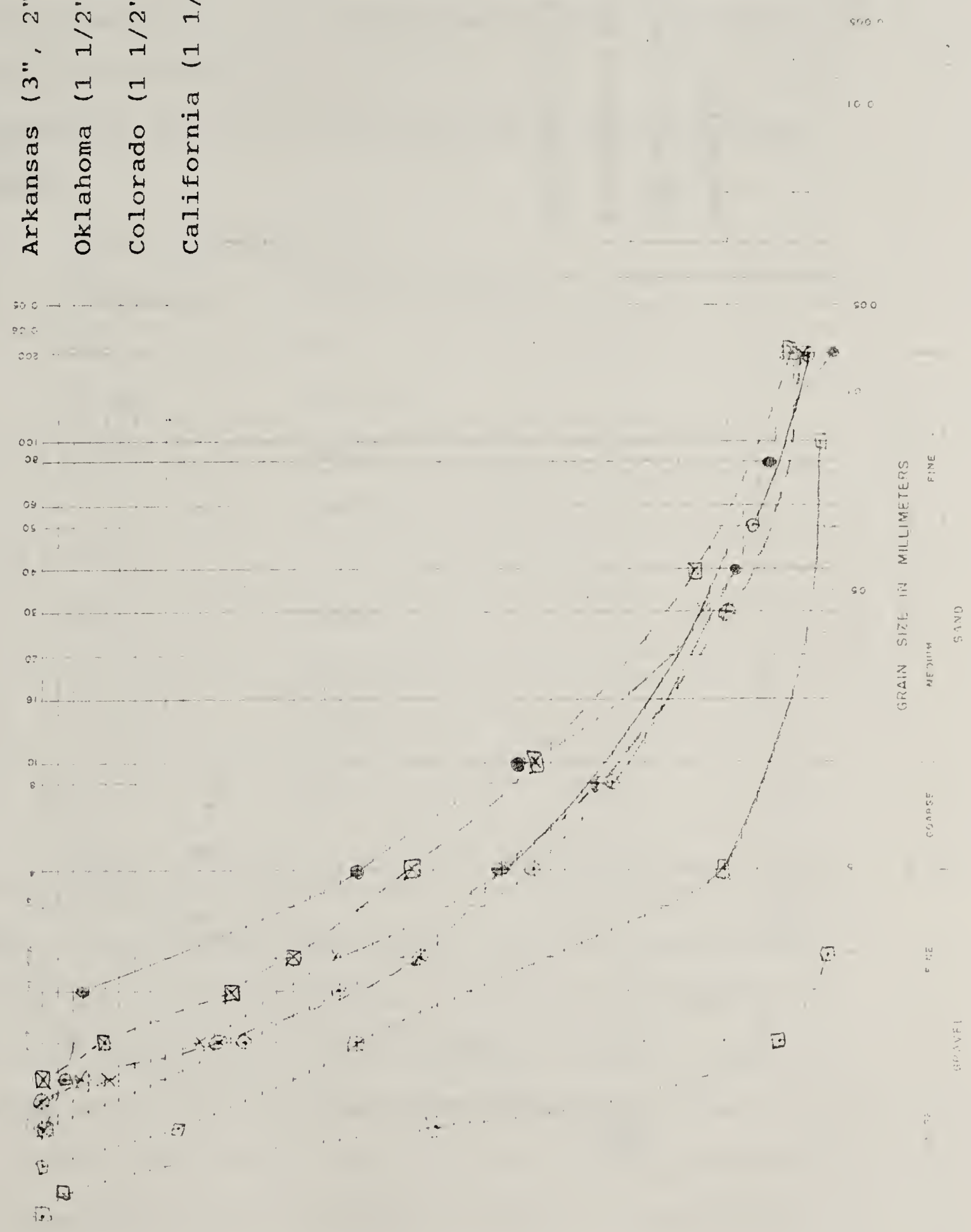


Figure G1. Comparison of Aggregate Gradations Used By Different States

GRADATION CURVE

SIEVE ANALYSIS	
SIZE OF OPENINGS IN INCHES	NUMBER OF MESH - U.S. STANDARD

Texas (2") □  
 Texas (1 3/4") ●  
 Kentucky (2") X  
 Tennessee (2") O

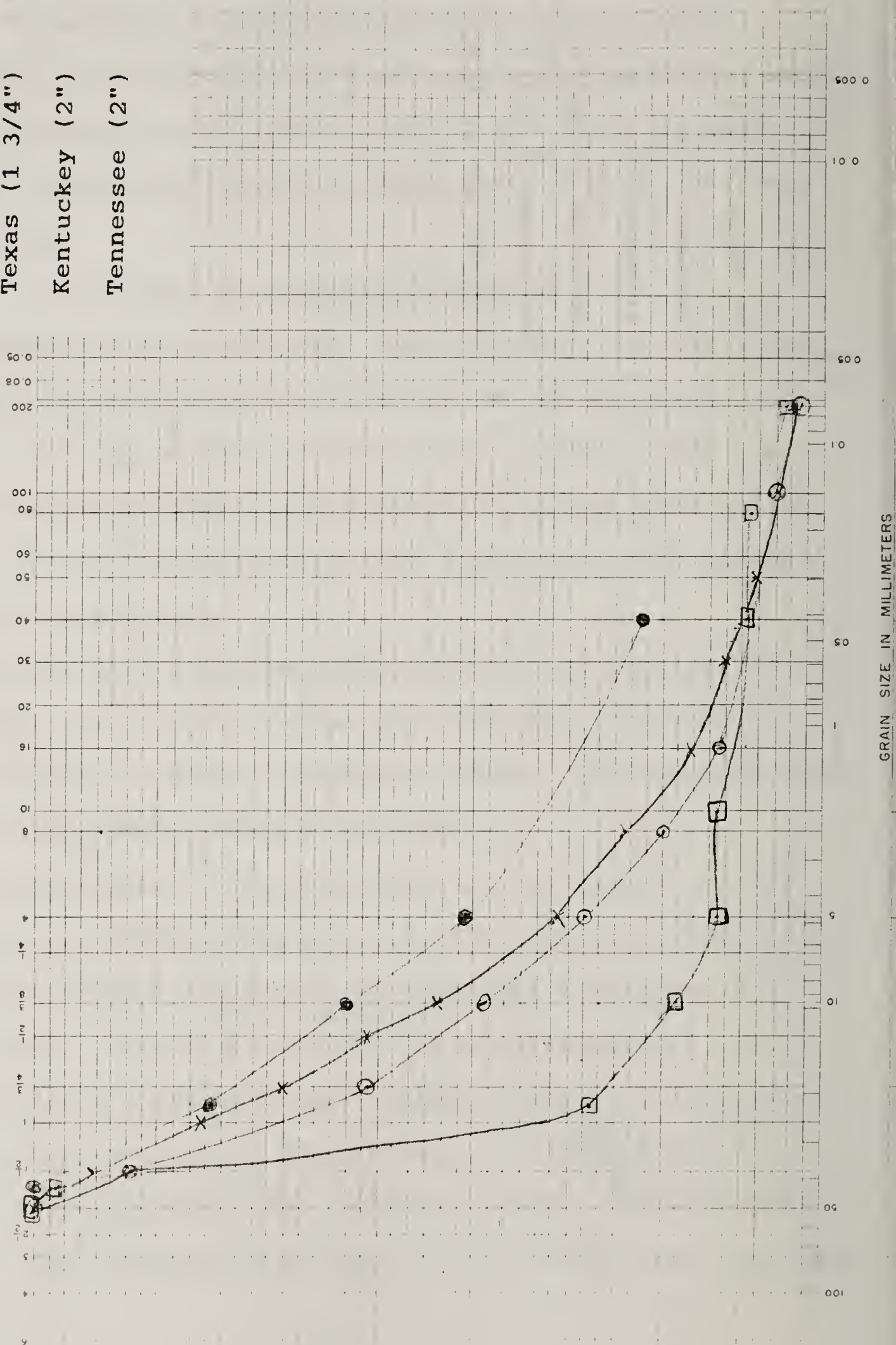


Figure G2. Comparison of Aggregate Gradations Used By Different States

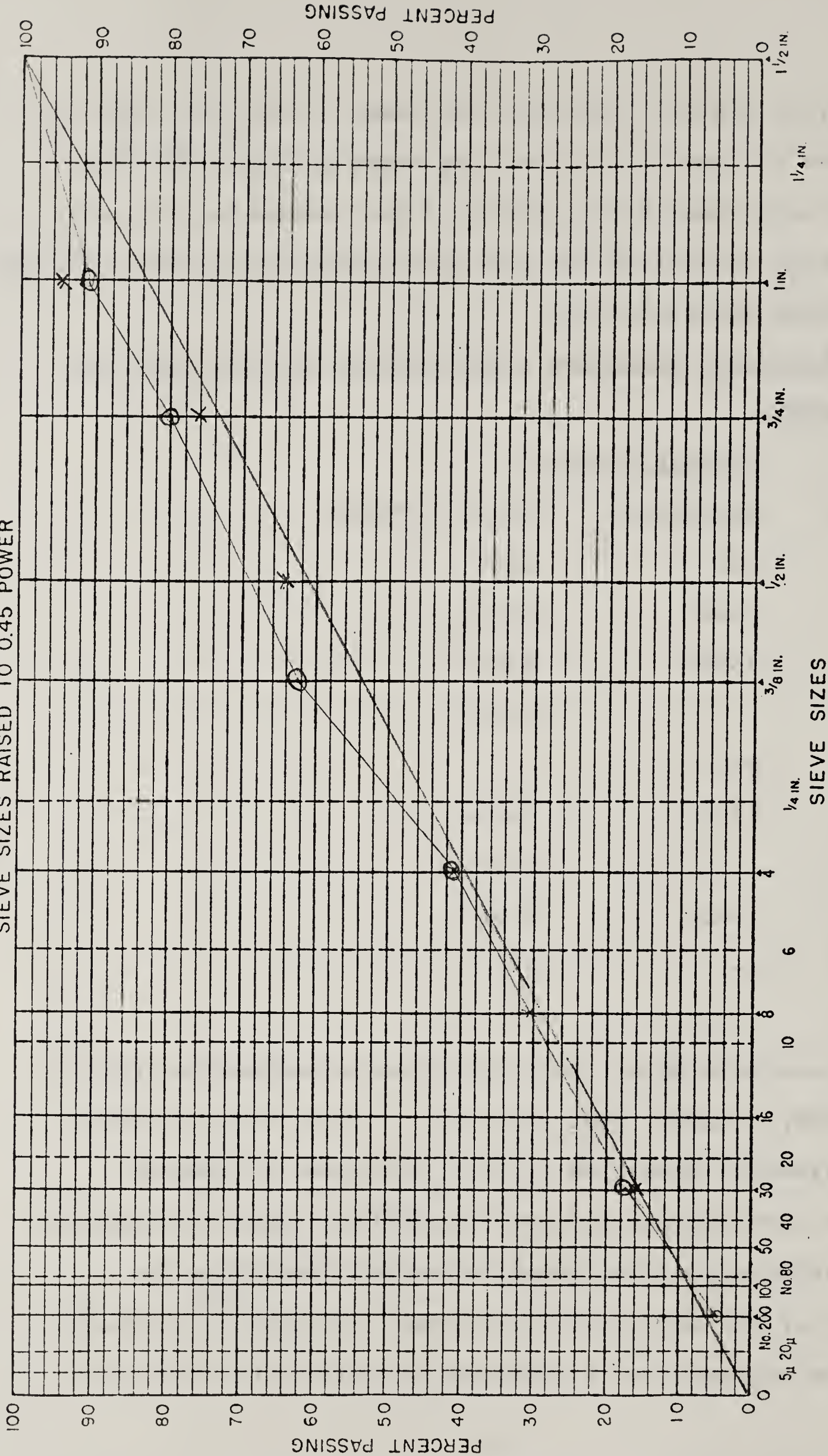
by the City of Denver. These two are shown in Table G1. The 0.45 power curves of these gradations are shown in Figure G3. The laboratory experiment of the Marshall Test Method on the large stone mix with unmodified and modified asphalt was conducted with the California specification.

**Table G1. Aggregate Gradation Specification of California and City of Denver.**

<u>Sieve Size</u>	<u>Percent Passing</u>	
	<u>California</u>	<u>City of Denver</u>
1 1/2"	100	100
1"	88-95	90-100
3/4"	75-85	62-90
1/2"		50-78
3/8"	55-70	
# 4	32-50	28-54
# 8		20-42
# 30	10-24	8-24
# 200	2-7	1-9

Sieve analysis of all four fractions of aggregates (large stone, coarse, crushed fine, and natural fine) were performed. The mean values of gradation of four fractions of crushed Yellowstone river gravel and natural sand are shown in Table G2. The large stone aggregate gradation was obtained from the combination of the above four fractions. In doing so, certain sizes of the aggregate were produced in excess to obtain the

GRADATION CHART  
SIEVE SIZES RAISED TO 0.45 POWER



Identification of gradations:

California (O)  
City of Denver (X)

THIS SYMBOL IDENTIFIES SIMPLIFIED PRACTICE AND COMPATIBLE SIEVE SIZES

Sheet No.
Date

Figure G3. First Gradation of Large Stone Aggregates on a 0.45 Power Curve.

Table G2. Gradation of Three Fractions of Aggregate Received from E.E. St. Johns Pit and Large Stone Received from Prince Paving Co., Forsyth.

Fraction -----	Percent Retained			
	Prince Large Stone -----	EE St. Johns Coarse    Crushed    Natural Aggregate   Fine    Fine -----		
Sieve -----				
1 1/2"	13.74			
1"	49.23			
3/4"	23.84			
3/8"	8.05	76.06	0.23	4.51
# 4	1.25	22.18	2.33	15.78
#30	1.71	1.29	58.33	12.52
#200	1.27	0.00	30.01	62.06
Pan	0.90	0.47	9.11	5.13

desired gradation. These excess amounts of the aggregate were wasted. The blend of aggregate required to produce the desired mix gradation from each separate aggregate fraction was computed using full gradation for each separate aggregate and by trial and error. (7)

It was found that 25 percent of crushed fine, 20 percent of large stone, 5 percent natural fine, and 50 percent of coarse aggregate were required to produce the desired mix gradation. The actual mix gradation and desired mix gradation are shown in Table G3.

As seen in the 0.45 power curve of the first gradation, Figure G3, the aggregate gradation was above the maximum density line except for minus #200 sieve size fines. The density of the specified gradation was less than maximum and voids would not be lowest.

A trial set of Marshall mix design tests with three different gradations was conducted for the selection of the second gradation of aggregates. Unmodified Cenex was used for this trial test. Three aggregate gradations A, B and C are shown in Table G4. The 0.45 power curves for these three gradations are shown in Figures G4 and G5. The gradations "A", "B", and "C" represent the maximum density, hump gradation at #30, and skip gradation respectively in the 0.45 power curve. The Marshall test results are presented in Table G5. Maximum stability and density were achieved in gradation "A" as shown in Figures G6 and G7. Thus gradation "A" was selected for the second gradation. It was

Table G3. Aggregate Mix Gradation Obtained After Blending Three Fractions from EE St. Jones Pit and Large Stone Fraction from Prince Paving Co. and Desired Aggregate Mix Gradation.

Sieve	Desired Specification	Mix Gradation
1 1/2"	0.00	0.00
1"	8.50	8.50
3/4"	11.50	11.17
3/8"	17.50	17.50
# 4	21.50	19.97
#30	24.00	22.10
#200	12.40	13.02
Pan	4.50	4.01

Table 64. Selection of Second Gradation Aggregates from Three Alternatives Based on the 0.45 Power Curve.

Sieve Size	Gradation "A" Percent Passing	Gradation "B" Percent Passing	Gradation "C" Percent Passing
1"	83.5	82.0	82.0
3/4"	73.0	70.0	70.0
1/2"	61.0	57.0	57.0
3/8"	53.0	49.0	49.0
#4	39.0	33.5	33.0
#8	28.5	22.0	28.0
#16	21.0	18.0	20.0
#30	15.5	15.5	14.0
#200	6.0	5.0	5.0

GRADATION CHART  
SIEVE SIZES RAISED TO 0.45 POWER

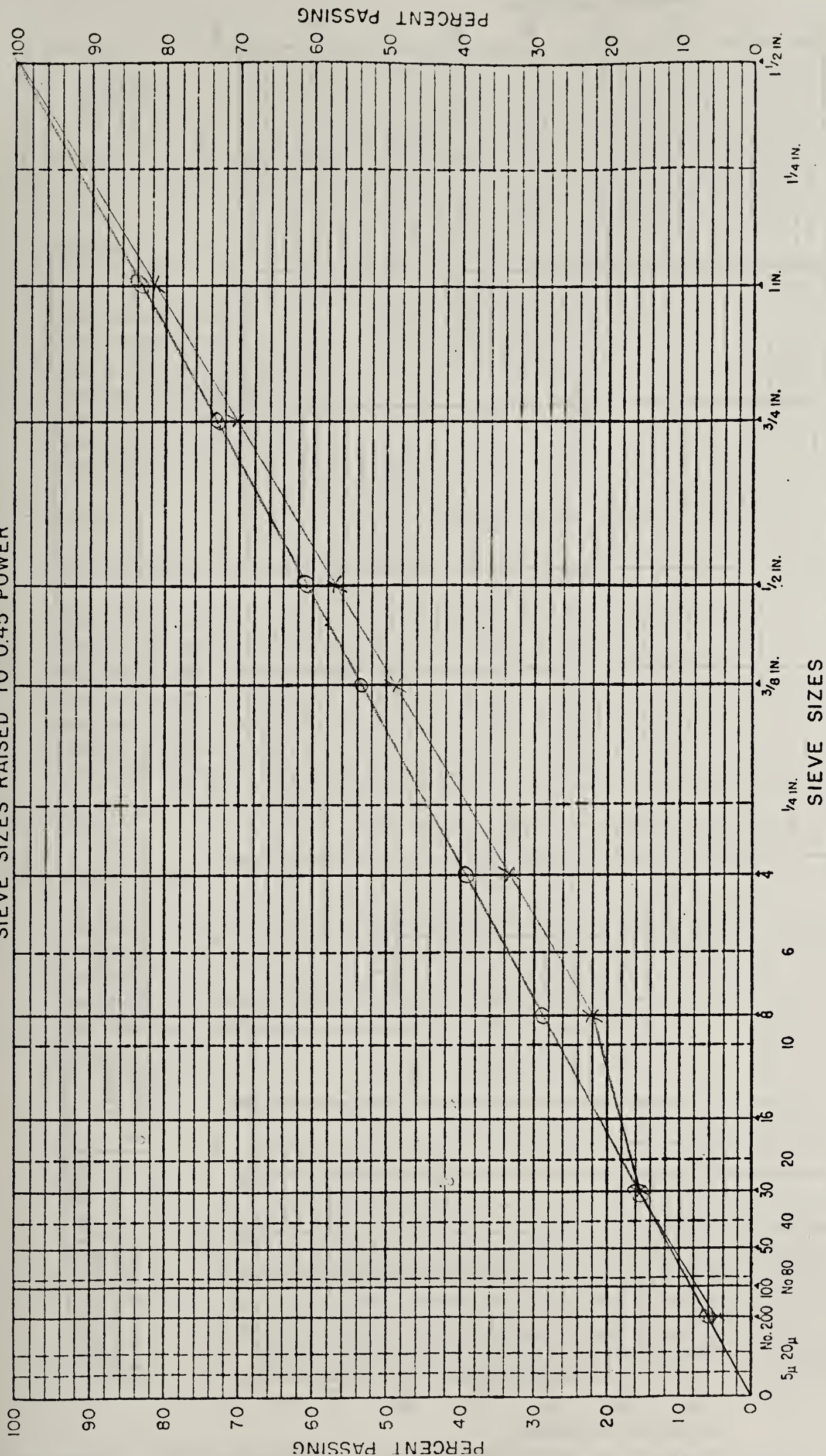


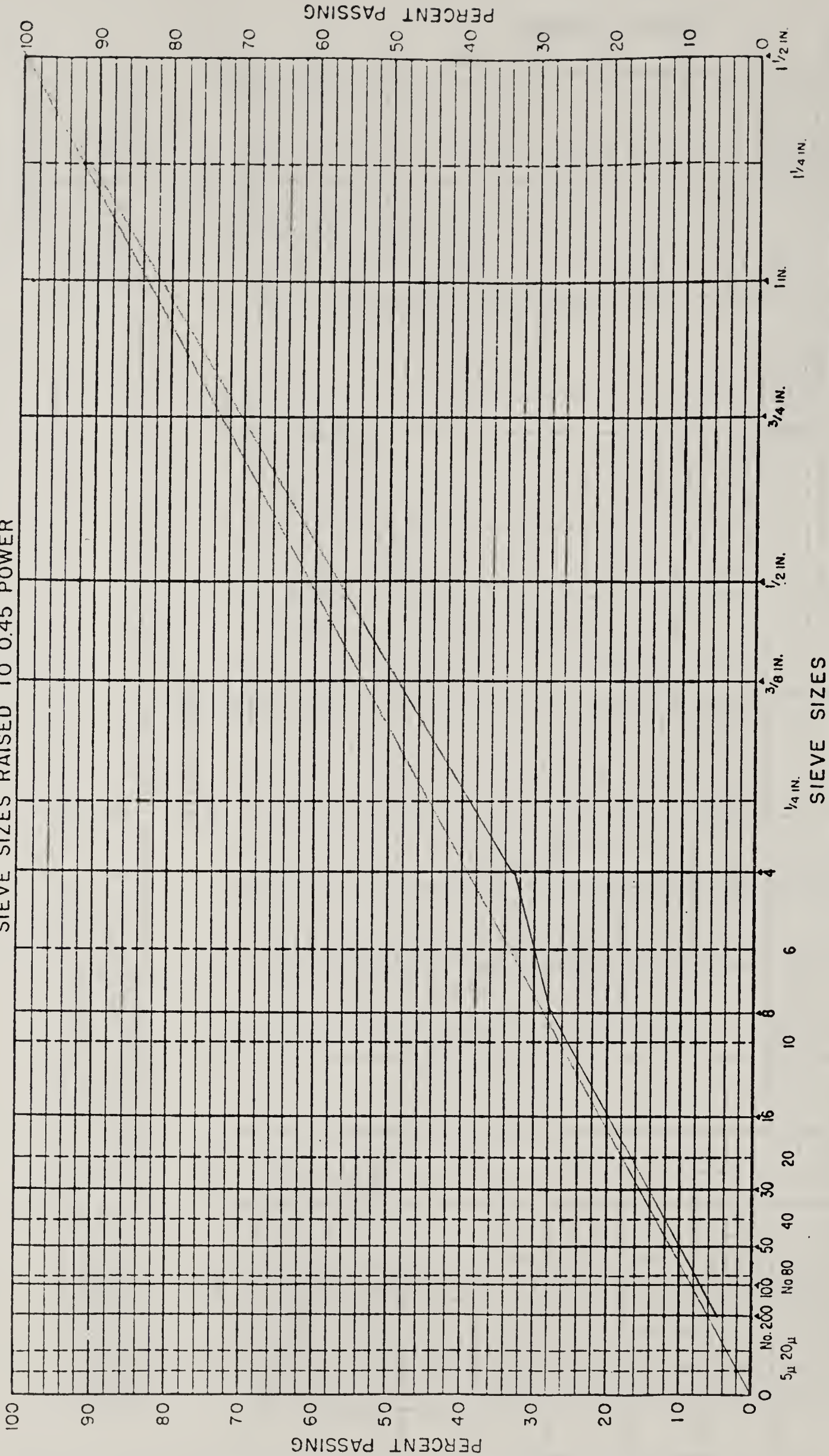
Figure G4. Trial Gradation of Large Stone Aggregates "A" and "B"  
Based on a 0.45 Power Curves.

Sheet No.
Date

Identification of gradations:
Trial Gradations A ○
Trial Gradation B ×

THIS SYMBOL IDENTIFIES SIMPLIFIED PRACTICE AND COMPATIBLE SIEVE SIZES
---

GRADATION CHART  
SIEVE SIZES RAISED TO 0.45 POWER



Identification of gradations:

Trial Gradation C

▲ THIS SYMBOL  
IDENTIFIES SIMPLIFIED  
PRACTICE AND  
COMPATIBLE SIEVE SIZES

Sheet No.
Date

Figure G5. Trial Gradation of Large Stone Aggregates "C" Based on a 0.45 Power Curves.

Table G5. Trial Marshall Test Results for Selection of Second Gradation Aggregates with

-----  
 Tests                                      Unmodified Cenex 120/150 - Gradation "A" - 75 Blow

Asphalt Content	4.00%	4.50%	5.00%
Mean Marshall Stability in lbs.	4923.17	4596.17	3426.67
Standard Dev. Marshall Stability	83.25	457.05	243.64
Mean Marshall Flow in 1/100 inch.	13.00	13.67	16.00
Standard Deviation Marshall Flow	1.00	1.15	1.00
Mean Bulk Specific Gravity	2.416	2.414	2.414
Standard Deviation Bulk Sp. Gr.	0.007	0.003	0.006
Unit Weight in Pcf.	150.76	150.63	150.63

Tests                                      Unmodified Cenex 120/150 - Gradation "B" - 75 Blow

Asphalt Content	4.00%	4.50%	5.00%
Mean Marshall Stability in lbs.	4251.00	3728.75	3188.80
Standard Dev. Marshall Stability	475.12	914.20	222.20
Mean Marshall Flow in 1/100 inch.	13.67	14.33	14.33
Standard Deviation Marshall Flow	2.31	3.06	0.58
Mean Bulk Specific Gravity	2.412	2.401	2.407
Standard Deviation Bulk Sp. Gr.	0.011	0.006	0.004
Unit Weight in Pcf.	150.51	149.82	150.20

Tests                                      Unmodified Cenex 120/150 - Gradation "C" - 75 Blow

Asphalt Content	4.00%	4.50%	5.00%
Mean Marshall Stability in lbs.	3815.00	3956.53	3476.17
Standard Dev. Marshall Stability	144.19	356.94	290.40
Mean Marshall Flow in 1/100 inch.	11.67	14.33	16.67
Standard Deviation Marshall Flow	0.06	2.08	2.08
Mean Bulk Specific Gravity	2.405	2.408	2.416
Standard Deviation Bulk Sp. Gr.	0.011	0.008	0.006
Unit Weight in Pcf.	150.51	149.82	150.20

## Trial for Selection of II Grad.

### Stability for Gradation 'A', 'B', 'C'.

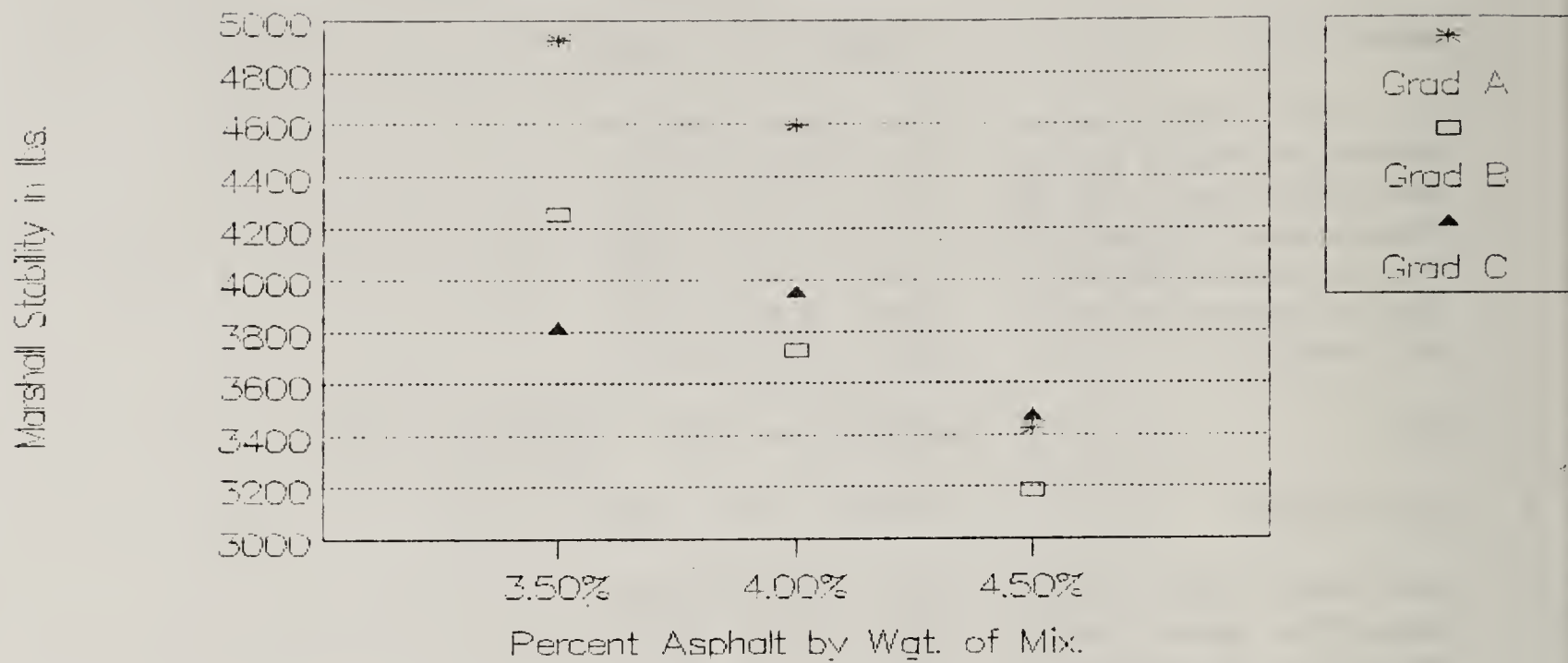


Figure G6. Stability of Trial Gradations A, B, and C.

## Trial for Selection of II Grad.

### Unit Weight for Gradation 'A', 'B', 'C'

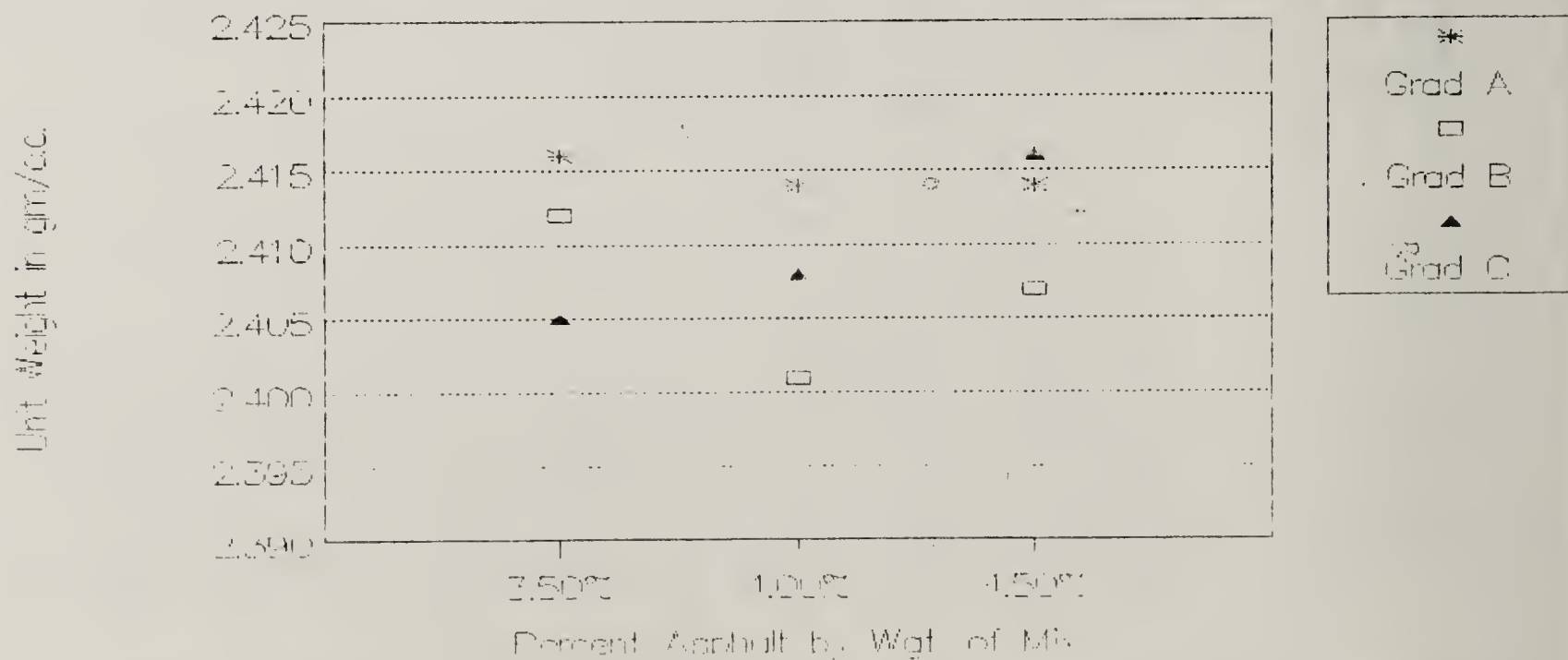


Figure G7. Unit Weight of Trial Gradations A, B, and C.

assumed that the effect of the modified asphalt would be reflected better with this maximum density gradation.

For the specimens prepared with the mineral filler, 1.4 percent by weight of mix was used in both gradations.

#### Marshall Method of Mix Design for 6-inch Specimens

The Pennsylvania Department of Transportation developed the equipment and procedure for testing 6-inch diameter specimens, in compliance with the general recommendation that the diameter of the mold should be at least four times the maximum nominal diameter of the coarsest aggregate in the mixture to be molded.(4)

In general, the same procedure as followed for the preparation of the four inch Marshall test specimen mold can be followed. For the six inch diameter mold, the height of the mold is 3 3/4", which gives the same diameter/height ratio as the four inch mold. A hammer weight of 22.5 lbs is used with a drop of 18". The samples with 75 and 112 blows compaction were prepared. This gives an energy input to the 6-inch specimen per unit volume which is similar to 50 and 75 blows on a 4-inch mold.(4)

About 4050 gm of mix is required to prepare a 6-inch Marshall specimen compared to about 1200 gm for a 4-inch mold.

The Kentucky Department of Highways stipulates the specification for a 6-inch molded specimen as follows:

Stability	3000 lbs. Minimum
Flow	28 Minimum

Air Void	4.5 +/- 1 percent
VMA	11.5 percent Minimum.

### Procedure

The AASHTO standard method of test procedure was followed in conducting the Marshall Mix Design Method and related tests. The AASHTO test number and test title are as follows:

<u>AASHTO</u>	<u>Test Title</u>
<u>Designation</u>	
T11 - 82	Amount of Material Finer Than 0.075 mm (# 200) Sieve in Aggregate.
T27 - 82	Sieve Analysis of Fine and Coarse Aggregate.
T166 -78(1982)	Bulk Specific Gravity of Compacted Bituminous Mixtures.
T209 - 82	Maximum Specific Gravity of Bituminous Paving Mixtures.
T269 - 80	Percent Air Voids in Compacted Dense and Open Bituminous Paving Mixtures.

In addition to these tests, the standard test method for resistance to plastic flow of bituminous mixture using Marshall apparatus for 6-inch diameter specimens Large Stone Asphalt Mixes: Design and Construction by Prithvi S. Kandhal was employed (4). Detail descriptions are given here to aid others, inexperienced in the more difficult task of preparing 6-inch specimens.

Scope: This method covers the measurement of the resistance to plastic flow of cylindrical specimens of bituminous paving mixtures loaded on the lateral surface by means of the Marshall

apparatus. This method is for use with mixtures containing asphalt cement and aggregate up to 2 inch maximum nominal size.

Significance and Use: This method is used in the laboratory mix design of bituminous mixtures. Specimens are prepared in accordance with the method and tested for maximum load and flow. Density and void properties may also be determined on the specimen prepared in accordance with the method. The testing section of this method can also be used to obtain maximum load and flow for bituminous paving specimens cored from the pavements or prepared by other methods. These results may differ from values obtained on specimens prepared by this method.(4)

Apparatus used in the MSU test conforms to the apparatus specified in the publication, except for the following differences in dimension of the base plate, hammer, and breaking head. The differences are as follows:

	<u>Specified Measurement</u>	<u>Actual Measurement</u>
Base plate thickness	0.25 inch	0.16"
Compaction hammer diameter	3.00"	2.90"
Compaction base diameter	5.88"	5.97"
Breaking head width	4.88"	4.5"
Breaking head thickness	.87"(min)	.95"

Other differences are indicated in Figure M1 by circled numbers. The Marshall equipment was manufactured by the Pine Instrument Company. The mixing apparatus is a 30 quart Hobart mixer, with a modified beater and warming attachment to accommodate the large

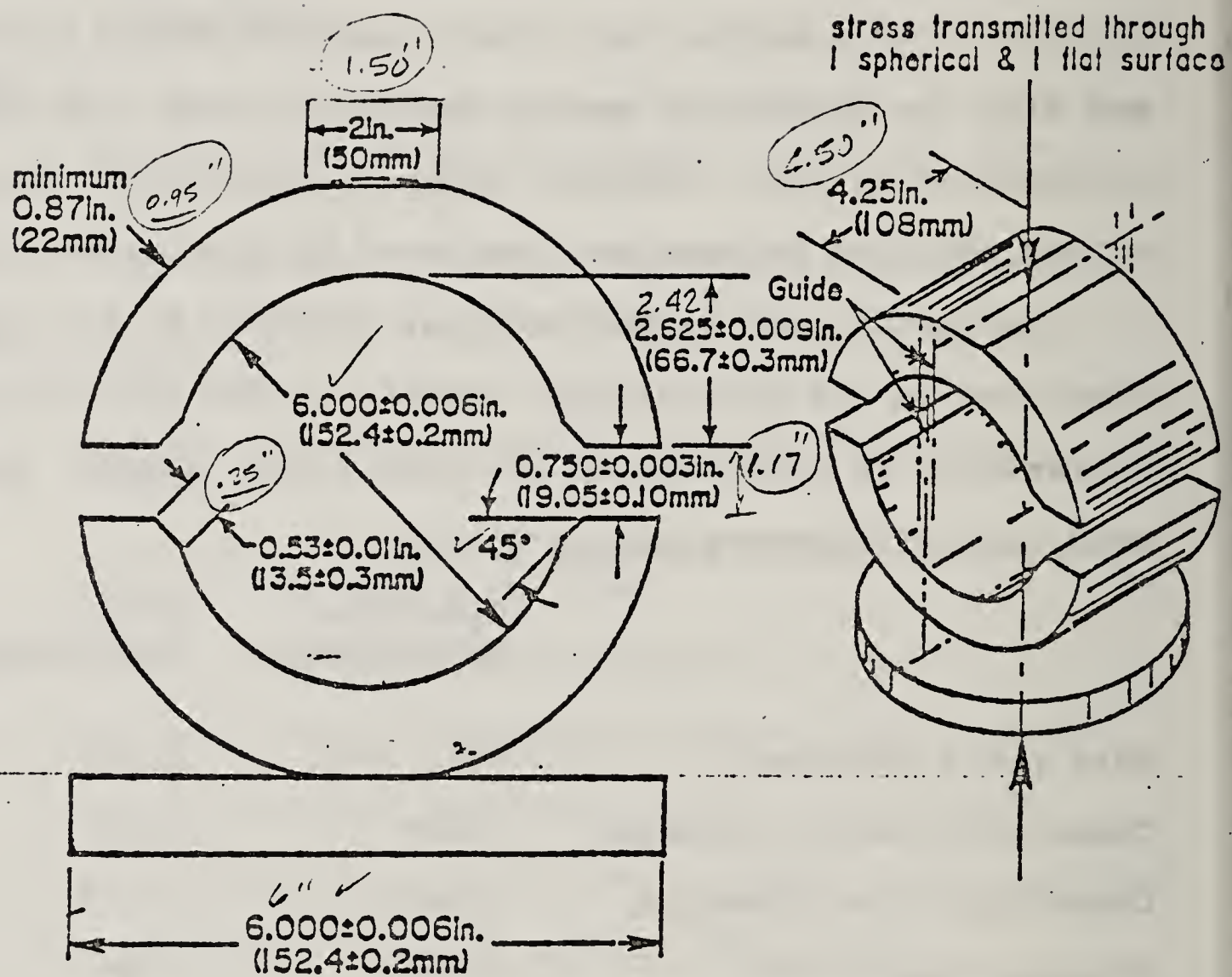


Figure M1. Diagram Illustrating the Dimensions of the Breaking Head for 6" Diameter Molded Specimen

stone.

### Preparation of the Marshall Test Specimens

Three specimens for each combination of aggregate and asphalt content were made. Dried aggregates, separated to desired size fraction, were weighed to obtain the mix of the specified aggregate composition. The weight of the different sizes of aggregate to obtain a sample of 3843 to 3845 gm. are as shown in Table M1.

Table M1. Weight of First and Second Gradations Aggregates by Size for a 6-inch Specimen

<u>First Gradation</u>			<u>Second Gradation</u>		
<u>Size</u>	<u>%</u>	<u>Weight in gm.</u>	<u>Size</u>	<u>%</u>	<u>Weight in gm.</u>
+1"	8.5%	329.4	+1"	16.5	639.4
+3/4"	11.5%	445.6	+3/4	10.5	406.9
+3/8"	17.5%	678.1	+1/2	12.0	465.0
+ #4	21.5%	833.1	+3/8	7.5	290.6
+ #30	24%	930.0	+ #4	14.5	561.9
+ #200	12.5%	484.4	+ #8	9.5	368.1
- #200	4.5%	142.2	+ #16	8.5	329.4
			+ #30	5.5	213.1
			+ #200	9.5	368.1
			- #200	6.0	202.5
(Where applicable)			Mineral Filler	1.4	54.6

The mixing and compacting temperatures used for the unmodified asphalt were also used for the modified asphalt. The temperature was predetermined based on the viscosity. About 3850

grams of aggregate were heated in the mixing bowl to about 350°F. The mixing and compacting temperature range used was 284-296°F for Cenex and 277-285°F for Conoco. The dried aggregate was mixed completely. The predetermined weight of asphalt was poured in the mixing bowl. The total weight of the mixture was about 4050 gm. The temperature of the aggregate and asphalt was recorded. The aggregate mix in the bowl was mixed for 1.5 minutes. The specimen mold assembly and compaction hammer were thoroughly cleaned and heated on the hot plate to about 250°F. A filter paper was placed in the bottom of the mold before the mixture was poured. Approximately one half of the batch was poured into the mold, then spaded vigorously with a heated spatula 10 times over the interior and 15 times around the perimeter. The second half of the mix was then poured into the mold and spaded as before; a filter paper was placed on the top. The temperature of the mixture immediately prior to compaction was checked for compliance with the compacting temperature. The mold assembly was placed on the compaction pedestal in the mold holder. 75 blows of compaction were applied. The mold assembly was reversed and repeated 75 blows on other side of the mold. The mold was then allowed to cool to room temperature over night. The specimen sample was removed from the mold on the sample extractor.

The bulk specific gravity, and Marshall stability and flow for each sample specimen were determined according to AASHTO T166-78(82) and AASHTO T245-82 respectively. The stability correction ratio was used to determine the correct stability for

a 3 3/4-inch thick specimen.

### **Difficulties experienced**

The Hobart mixer was unable to mix the aggregate asphalt mixture due to the entrapment of the large stones between the side of the bowl and the beater. This difficulty was eliminated by trial and error modification of the beater, at significant cost and time and money.

The mixing bowl is large and thin-walled, which caused the sample to cool rapidly; thus, it was difficult to maintain the mix temperature. This was corrected by using a heating lamp, mounted beneath the bowl on a specially constructed metal frame.

The capacity of the Rice specific gravity test flask is insufficient to test the entire 6-inch molded sample at one time. The sample was divided approximately in half and two Rice flasks were used to complete the test on a sample. The large stones caused the flasks to crack during placement and removal of the sample. Moreover, charging the flask required excessive time and effort. This problem was eliminated by purchasing two aluminum pycnometers with large lidded openings.

### **Results and Observations**

Marshall test specimens were prepared for each of the unmodified, Kraton modified and Polybilt modified asphalt using the first and second large stone aggregates and tested for Marshall mix properties. The total number of Marshall tests and parameter tests are as follows:

Marshall Test Specimen Mold

648

Bulk Specific Gravity	648
Marshall Stability	648
Marshall Flow	648
Rice Specific Gravity	<u>648</u>
Total	3240 + 300 Repetitions

The whole process of Marshall testing was randomized and the sampling scheme was prepared to minimize the effect of ignored variables (operator, equipment, and small differences of temperatures). Three asphalt variables were considered for this set of randomized testing. They were unmodified Cenex, Kraton and Polybilt modified Cenex. Another set of tests for Conoco was conducted in the same way.

The temperatures of asphalt, aggregate and mix were recorded. The Marshall samples were prepared at different compactions for each of the first and second gradation large stone aggregates: 75 blows, 112 blows, and 75 blows for the samples with mineral filler.

These Marshall test results for first and second gradation aggregates are shown in tabulated form. The mean and standard deviation of stability, flow, bulk specific gravity, Rice specific gravity, and air voids of three specimens at each asphalt content are presented in the tables. The unit weight in pounds per cubic foot and voids in mineral aggregate based on the assumption of bulk specific gravity of aggregate at 2.651 are also presented in the tables. The test property curves for hot-mix design for first and second gradation large stone aggregates

by the Marshall method are shown in Appendix B and C respectively. The optimum asphalt content for each of the modified and unmodified asphalt was computed from the curves.

The results and observations of the Marshall test properties for first and second gradation aggregates are dealt separately and presented and discussed in the subsequent sections.

### First Gradation Large Stone Aggregates

The first series of Marshall tests on 6-inch molded specimens were conducted with first gradation large stone aggregate. The large stone aggregates were produced from the Yellowstone River gravel. Most of the large stones, about 50 percent of 1 1/2-inch to 3/4-inch, were rounded gravel and with only one broken face.

### Specimens without Selected Large Stone Aggregates, 75 blows

#### Compaction

The first set of the tests were conducted with the large stone aggregates as they were, that is without selection. More attention was paid to the process of 6-inch specimen preparation, procedure and temperatures. The tests were conducted with the large range of asphalt contents 4.5 to 6.5 percent for unmodified and modified, Cenex and Conoco. The test results for the batch of unmodified and modified Cenex are presented in Table M2. Maximum stability value for unmodified Cenex, 3831, and Kraton modified Cenex (Kr-Ce), 4244 occurred at 5.5 percent asphalt content, whereas that for Polybilt modified Cenex (Po-Ce), 3902, occurred at 5 percent asphalt content. The standard deviations of

Table M2. Marshall Test Results-First Gradation without Selected Aggregates for Cenex. 75-Blow.

Tests	Unmodified Cenex 120/150				
Asphalt Content	4.50%	5.00%	5.50%	6.00%	6.50%
Mean Marshall Stability in lbs.	3215.30	3718.75	3831.60	3200.67	3160.00
Standard Dev. Marshall Stability	161.90	420.00	548.00	274.20	446.00
Mean Marshall Flow in 1/100 inch.	11.30	14.00	14.33	14.67	16.67
Standard Deviation Marshall Flow	0.57	2.00	2.08	2.08	1.53
Mean Bulk Specific Gravity	2.363	2.384	2.387	2.397	2.394
Standard Deviation Bulk Sp. Gr.	0.007	0.008	0.008	0.011	0.004
Unit Weight in Pcf.	147.45	148.76	148.95	149.57	149.39
Mean Rice Specific Gravity	2.500	2.463	2.449	2.440	2.428
Standard Deviation Rice Sp. Gr.	0.007	0.011	0.016	0.010	0.011
Mean Percent Air Voids	5.51	3.20	2.52	1.77	1.28
Standard Deviation % Air Voids	0.26	0.27	0.45	0.07	0.28
VMA*	14.87	14.57	14.91	15.01	15.56

Tests	Kraton Modified Cenex				
Mean Marshall Stability in lbs.	3639.33	3760.20	4244.10	3156.00	3142.00
Standard Dev. Marshall Stability	74.33	540.40	361.00	471.82	179.70
Mean Marshall Flow in 1/100 inch.	16.67	15.00	18.33	19.67	22.00
Standard Deviation Marshall Flow	4.73	1.00	0.57	4.04	3.61
Mean Bulk Specific Gravity	2.355	2.365	2.384	2.375	2.382
Standard Deviation Bulk Sp. Gr.	0.006	0.005	0.003	0.011	0.006
Unit Weight in Pcf.	146.95	147.58	148.76	148.20	148.64
Mean Rice Specific Gravity	2.474	2.454	2.433	2.420	2.413
Standard Deviation Rice Sp. Gr.	0.002	0.018	0.012	0.006	0.009
Mean Percent Air Voids	4.82	3.60	2.02	1.87	1.30
Standard Deviation % Air Voids	0.03	0.51	0.47	0.69	0.25
VMA*	15.16	15.25	15.02	15.79	15.99

Tests	Polybilt Modified Cenex				
Mean Marshall Stability in lbs.	3666.75	3903.20	3886.80	3877.80	3433.40
Standard Dev. Marshall Stability	211.50	391.30	446.50	574.90	376.00
Mean Marshall Flow in 1/100 inch.	14.00	13.67	17.67	15.67	20.00
Standard Deviation Marshall Flow	2.00	1.15	2.52	1.53	3.61
Mean Bulk Specific Gravity	2.359	2.391	2.377	2.381	2.379
Standard Deviation Bulk Sp. Gr.	0.008	0.003	0.005	0.011	0.004
Unit Weight in Pcf.	147.20	149.20	148.32	148.57	148.45
Mean Rice Specific Gravity	2.480	2.459	2.441	2.438	2.413
Standard Deviation Rice Sp. Gr.	0.014	0.009	0.009	0.003	0.011
Mean Percent Air Voids	5.05	2.79	2.61	1.97	1.90
Standard Deviation % Air Voids	0.61	0.35	0.32	0.39	0.55
VMA*	15.02	14.32	15.27	15.57	16.09

\* VMA values are based on assumed bulk specific gravity of aggregate = 2.651

stability were high at 5.5 percent Cenex, 5 percent Kr-Ce, and 6 percent Po-Ce. The differences between the maximum and minimum stability were 671 for unmodified Cenex, 1102 for Kr-Ce, and 470 for Po-Ce. The Kr-Ce was more sensitive to asphalt contents. Corresponding, differences for flow values were between 5.37 and 7. The mean and standard deviation of flow were relatively high. Four percent air voids was obtained at asphalt content between the level of 4.5 and 5 percent.

The test results for the 6-inch specimens with 75 blows compaction for unmodified and modified Conoco with first gradation large stone aggregates, without the selection of the broken faces, are shown in Table M3. The differences between the maximum and minimum values of stability with the asphalt content were 952 lbs. for unmodified Conoco, 809 lbs. for Kraton modified Conoco (Kr-Co), and 717 lbs. for Polybilt modified Conoco (Po-Co). The stability values for unmodified Conoco were more sensitive to the asphalt content. Similar differences for flow values were ranged between 6 and 8.67 hundredth of an inch.

The smooth test properties curves were drawn as shown in Appendix B. The optimum asphalt contents were computed from these curves for modified and unmodified, Cenex and Conoco. The test properties, stability, flow, unit weight, and percent air voids were determined from these curves and are shown in Table M4. The optimum asphalt contents were 5.41 for Cenex, 5.36 for Kr-Ce, and 4.87 percent for Po-Ce. Stability of Kr-Ce was highest at 4206. Flow values were in the range of 14 to 18. Unit weight ranged

Table M3. Marshall Test Results-First Gradation without Selected Aggregates for Conoco, 75-Blow.

Tests	Unmodified Conoco 120/150				
Asphalt Content	4.50%	5.00%	5.50%	6.00%	6.50%
Mean Marshall Stability in lbs.	2679.00	3275.60	3630.50	3307.00	2810.00
Standard Dev. Marshall Stability	240.00	371.60	261.00	876.00	198.70
Mean Marshall Flow in 1/100 inch.	18.67	12.33	14.00	15.79	19.00
Standard Deviation Marshall Flow	6.11	0.58	1.00	3.79	2.65
Mean Bulk Specific Gravity	2.349	2.381	2.392	2.391	2.380
Standard Deviation Bulk Sp. Gr.	0.009	0.011	0.010	0.007	0.004
Unit Weight in Pcf.	146.58	148.57	149.26	149.20	148.51
Mean Rice Specific Gravity	2.477	2.459	2.440	2.425	2.415
Standard Deviation Rice Sp. Gr.	0.006	0.008	0.004	0.012	0.004
Mean Percent Air Voids	5.15	3.17	1.97	1.39	1.45
Standard Deviation % Air Voids	0.52	0.56	0.39	0.29	0.31
VMA*	15.38	14.68	14.73	15.22	16.06
Tests	Kraton Modified Conoco				
Mean Marshall Stability in lbs.	3352.00	3731.67	4160.90	3940.70	3395.00
Standard Dev. Marshall Stability	478.00	430.80	36.10	420.90	763.00
Mean Marshall Flow in 1/100 inch.	17.00	16.67	17.00	18.67	22.67
Standard Deviation Marshall Flow	2.00	1.50	1.73	4.73	0.58
Mean Bulk Specific Gravity	2.336	2.364	2.382	2.392	2.375
Standard Deviation Bulk Sp. Gr.	0.027	0.009	0.006	0.004	0.006
Unit Weight in Pcf.	145.77	147.51	148.64	149.26	148.20
Mean Rice Specific Gravity	2.466	2.445	2.440	2.427	2.406
Standard Deviation Rice Sp. Gr.	0.003	0.014	0.005	0.013	0.005
Mean Percent Air Voids	5.25	3.30	1.64	1.51	1.31
Standard Deviation % Air Voids	1.13	0.50	0.76	0.44	0.31
VMA*	15.85	15.28	15.09	15.18	16.23
Tests	Polybilt Modified Conoco				
Mean Marshall Stability in lbs.	3802.4	3853.80	4159.25	3346.00	3441.90
Standard Dev. Marshall Stability	141.80	208.00	213.10	136.30	314.70
Mean Marshall Flow in 1/100 inch.	13.00	14.33	16.33	20.00	21.67
Standard Deviation Marshall Flow	1.00	1.50	0.58	2.65	1.53
Mean Bulk Specific Gravity	2.358	2.371	2.386	2.388	2.375
Standard Deviation Bulk Sp. Gr.	0.004	0.002	0.010	0.007	0.004
Unit Weight in Pcf.	147.14	147.95	148.89	149.01	148.20
Mean Rice Specific Gravity	2.477	2.448	2.442	2.419	2.402
Standard Deviation Rice Sp. Gr.	0.008	0.011	0.013	0.004	0.006
Mean Percent Air Voids	4.82	3.17	2.36	1.28	1.11
Standard Deviation % Air Voids	0.41	0.49	0.21	0.15	0.37
VMA*	15.06	15.03	14.95	15.33	16.23

\* VMA values are based on assumed bulk specific gravity of aggregate = 2.651

1990 Asphalt

Table M4. Optimum Asphalt Content-First Gradation Aggregates without Selected Large Stone, 75-Blow Compaction, and Mix Properties at Optimum Asphalt Content.

Asphalt	Cenex	Kraton Modified Cenex	Polybilt Modified Cenex	Conoco	Kraton Modified Conoco	Polybilt Modified Conoco
Max. Marshall Stability at Percent	5.50	5.50	5.00	5.50	5.50	5.50
Max. Unit Weight at Percent	6.00	5.82	5.00	5.50	5.50	6.00
4 Percent Air Voids at Percent	4.73	4.75	4.61	4.17	4.73	4.68
Average Optimum Asphalt Content	5.41	5.36	4.87	5.26	5.24	5.39

Properties of the Mix at Optimum Asphalt Content

Marshall Stability in lbs.	3825.00	4206.00	3875.00	3540.54	4054.54	4111.11
Marshall Flow in 1/100 Inch.	14.40	17.83	14.15	13.20	17.71	15.84
Unit Weight in gm/cc	2.392	2.381	2.389	2.390	2.374	2.384
Unit Weight in Pcf	149.26	148.57	149.07	149.14	148.14	148.76
Percent Air Voids in Percent	2.55	2.58	3.20	2.59	2.54	2.35
VMA	14.80	15.15	14.50	15.00	15.20	15.00

from 2.381 to 2.391 gm/cc, and air voids 2.55 to 3.20 percent. Similarly, the stability of both modified Conoco, 4055 for Kr-Co, and 4111 for Po-Co, were higher compared to unmodified Conoco, 3540. The flow value ranged from 13.2 for unmodified Conoco to 17.71 for Kr-Co. The unit weight ranged between 2.374 and 2.390, and percent air voids were 2.35 and 2.59.

#### Specimens with Selected Large Stone Aggregates and 75 Blows

##### Compaction

The test results of Cenex asphalt and first gradation selected aggregates for at least two broken faces, with 75 blows compaction are shown in Table M5. Four percent air voids were achieved at asphalt content between 4.5 and 5 percent. The tests were conducted at four different asphalt contents (4.5, 5, 5.5, and 6 percent). The standard deviation of stability of unmodified Cenex was higher than that of modified Cenex. The unmodified and Polybilt modified Cenex were more sensitive to the asphalt content. The relative differences of stability, unit weight and air voids between the unmodified and modified Cenex at different asphalt contents are shown in Figures M2, M3, and M4 respectively.

The test property curves were relatively smooth as shown in Appendix B. It is also noted that stability reduces more rapidly as asphalt content increases. The difference between maximum and minimum values of stability of the Cenex and Polybilt modified Cenex are about 1000 lbs. This indicates that the stability of Cenex and Polybilt modified Cenex is more sensitive to the

Table M5. Marshall Test Results-Cenex with Selected 1st. Gradation Aggregates, 75-Blow.

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 Tests                                      Unmodified Cenex 120/150 75 Blow Compaction

Asphalt Content	4.50%	5.00%	5.50%	6.00%
Mean Marshall Stability in lbs.	4789.42	4637.50	4318.83	3798.33
Standard Dev. Marshall Stability	469.88	437.85	436.88	618.84
Mean Marshall Flow in 1/100 inch.	13.33	14.33	15.00	16.00
Standard Deviation Marshall Flow	1.53	0.58	2.00	1.00
Mean Bulk Specific Gravity	2.374	2.388	2.393	2.391
Standard Deviation Bulk Sp. Gr.	0.005	0.007	0.013	0.009
Unit Weight in Pcf.	148.14	149.01	149.32	149.20
Mean Rice Specific Gravity	2.481	2.463	2.446	2.439
Standard Deviation Rice Sp. Gr.	0.008	0.009	0.013	0.004
Mean Percent Air Voids	4.30	3.73	2.56	1.98
Standard Deviation % Air Voids	0.20	0.55	1.01	0.49
VMA*	14.48	14.42	14.70	15.22

## Tests                                      Kraton Modified Cenex 75 Blow Compaction

Mean Marshall Stability in lbs.	4231.58	4323.67	4083.25	3978.75
Standard Dev. Marshall Stability	233.65	220.60	185.70	235.32
Mean Marshall Flow in 1/100 inch.	15.33	15.33	18.67	20.00
Standard Deviation Marshall Flow	1.15	0.58	4.04	2.00
Mean Bulk Specific Gravity	2.356	2.376	2.384	2.378
Standard Deviation Bulk Sp. Gr.	0.007	0.004	0.007	0.007
Unit Weight in Pcf.	147.01	148.26	148.76	148.39
Mean Rice Specific Gravity	2.471	2.447	2.434	2.417
Standard Deviation Rice Sp. Gr.	0.011	0.008	0.009	0.002
Mean Percent Air Voids	4.65	2.89	2.05	1.61
Standard Deviation % Air Voids	0.69	0.46	0.43	0.26
VMA*	15.13	14.85	15.02	15.68

## Tests                                      Polybilt Modified Cenex 75 Blow Compaction

Mean Marshall Stability in lbs.	4514.00	4054.50	4372.50	3579.80
Standard Dev. Marshall Stability	107.14	26.50	173.00	414.94
Mean Marshall Flow in 1/100 inch.	13.67	16.67	16.67	16.67
Standard Deviation Marshall Flow	2.08	0.58	1.53	0.58
Mean Bulk Specific Gravity	2.368	2.392	2.387	2.381
Standard Deviation Bulk Sp. Gr.	0.010	0.006	0.004	0.010
Unit Weight in Pcf.	147.76	149.26	148.95	148.57
Mean Rice Specific Gravity	2.480	2.464	2.438	2.429
Standard Deviation Rice Sp. Gr.	0.006	0.002	0.003	0.006
Mean Percent Air Voids	4.50	2.95	2.09	1.97
Standard Deviation % Air Voids	0.41	0.16	0.29	0.19
VMA*	14.69	14.28	14.91	15.57

\* VMA values are based on assumed bulk specific gravity of aggregate = 2.651

## Effect of Modifier on Stability—75 Blow Cenex with 1st Gradation Aggregate

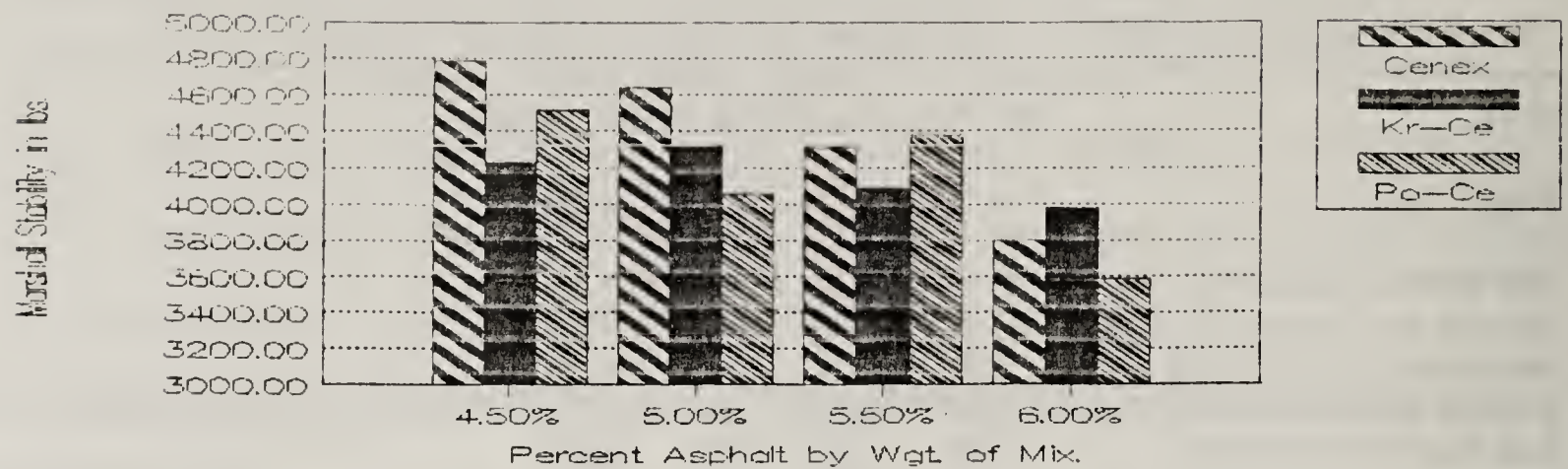


Figure M2. Stability at Different Asphalt Content for First Gradation of Selected Aggregates and Cenex.

## Modifier on Unit Weight — 75 Blow. Cenex with 1st Gradation Aggregate

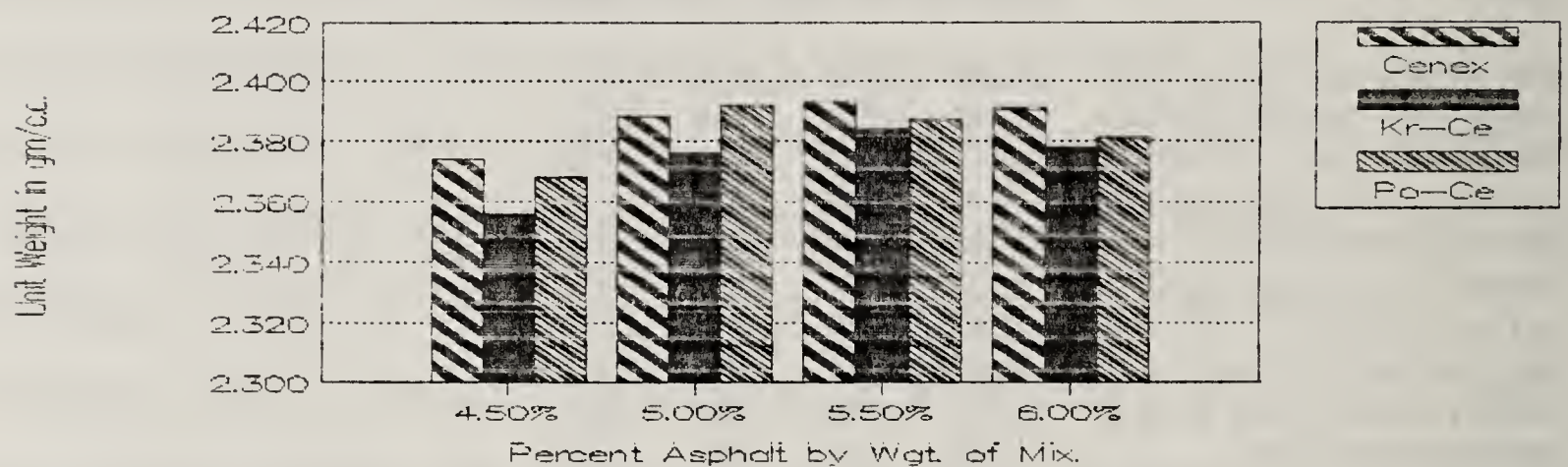


Figure M3. Unit Weight at Different Asphalt Content for First Gradation of Selected Aggregates and Cenex.

## Modifier on Percent Air Voids — 75 Blow Cenex with 1st Gradation Aggregate

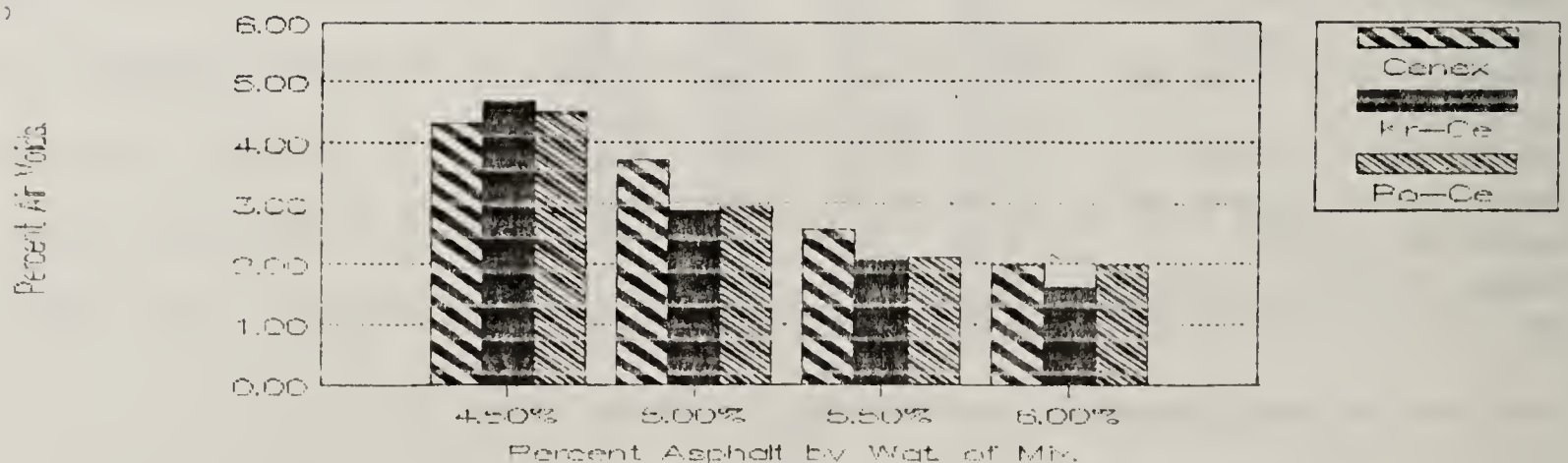


Figure M4. Air Voids at Different Asphalt Content for First Gradation of Selected Aggregates and Cenex.

asphalt content. Similar observations can be made for density, flow and voids. It is observed that the maximum unit weight is within 5 to 6 percent asphalt content. The standard deviation was quite low. The mean void ratio at 4.5 percent asphalt content was above 4 percent in all cases.

It is observed that the VMA follows a minimum value pattern in all the cases. The mean Rice specific gravity decreases as the asphalt content increases in all the cases.

The test property curves were drawn for each parameter. All of them followed the general pattern: maximum peak curves for stability and density, decreasing curve pattern with increasing asphalt content for void ratio, increasing pattern for flow with increasing asphalt content, and minimum curve for the VMA. The curves are relatively smooth as shown in Appendix B.

Table M6 shows the test results of modified and unmodified Conoco with first gradation aggregates at 75 blows compaction. It is observed that the standard deviation of the test properties values are low in all cases. The stability of modified Conoco is higher than that of unmodified Conoco.

The optimum asphalt content for each of unmodified and modified Cenex and Conoco was computed from the test property curves. Table M7 shows the optimum asphalt content computation. These values are low 4.71 to 5.04. The Marshall stability of the unmodified Cenex is higher than that of Kraton and Polybilt modified Cenex. Whereas the stability of modified Conoco is better than unmodified Conoco. Thus, modification of Conoco

Table M6. Marshall Test Results-Conoco with Selected First Gradation Aggregates, 75 Blows.

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 Tests Unmodified Conoco 120/150 - 75 Blow Compaction
 

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Asphalt Content	4.50%	5.00%	5.50%	6.00%
Mean Marshall Stability in lbs.	4119.75	4170.50	3948.50	3453.83
Standard Dev. Marshall Stability	85.52	335.59	216.90	293.10
Mean Marshall Flow in 1/100 inch.	12.00	13.00	13.00	14.67
Standard Deviation Marshall Flow	1.00	1.00	1.00	1.15
Mean Bulk Specific Gravity	2.374	2.401	2.398	2.391
Standard Deviation Bulk Sp. Gr.	0.016	0.013	0.002	0.004
Unit Weight in Pcf.	148.14	149.82	149.64	149.20
Mean Rice Specific Gravity	2.477	2.461	2.449	2.428
Standard Deviation Rice Sp. Gr.	0.002	0.004	0.003	0.006
Mean Percent Air Voids	4.17	2.45	2.06	1.55
Standard Deviation % Air Voids	0.59	0.56	0.09	0.17
VMA*	14.48	13.96	14.52	15.22

## Tests Kraton Modified Conoco - 75 Blow Compaction

Mean Marshall Stability in lbs.	4657.75	4390.80	4341.80	3998.40
Standard Dev. Marshall Stability	420.00	276.00	238.20	365.80
Mean Marshall Flow in 1/100 inch.	14.33	15.00	15.67	18.33
Standard Deviation Marshall Flow	0.58	1.73	0.58	2.08
Mean Bulk Specific Gravity	2.361	2.383	2.387	2.387
Standard Deviation Bulk Sp. Gr.	0.008	0.006	0.008	0.005
Unit Weight in Pcf.	147.33	148.70	148.95	148.95
Mean Rice Specific Gravity	2.462	2.449	2.422	2.410
Standard Deviation Rice Sp. Gr.	0.002	0.009	0.007	0.002
Mean Percent Air Voids	4.12	2.67	1.44	0.94
Standard Deviation % Air Voids	0.31	0.40	0.18	0.26
VMA*	14.95	14.60	14.91	15.36

## Tests Polybilt Modified Conoco - 75 Blow Compaction

Mean Marshall Stability in lbs.	4537.2	4293.00	4054.00	3965.50
Standard Dev. Marshall Stability	320.30	140.22	165.70	226.50
Mean Marshall Flow in 1/100 inch.	13.33	14.00	16.33	18.33
Standard Deviation Marshall Flow	0.58	1.00	2.31	1.15
Mean Bulk Specific Gravity	2.373	2.388	2.391	2.387
Standard Deviation Bulk Sp. Gr.	0.007	0.006	0.003	0.002
Unit Weight in Pcf.	148.08	149.01	149.20	148.95
Mean Rice Specific Gravity	2.479	2.452	2.440	2.427
Standard Deviation Rice Sp. Gr.	0.010	0.008	0.004	0.005
Mean Percent Air Voids	4.09	2.58	2.00	1.67
Standard Deviation % Air Voids	0.73	0.45	0.12	0.14
VMA*	14.51	14.42	14.77	15.36

\* VMA values are based on assumed bulk specific gravity of aggregate = 2.651

Table M7. Optimum Asphalt Content-First Gradation Aggregates with Selected Large Stone.  
75 Blows Compaction, and Mix Properties at Optimum Asphalt Content.

Asphalt	Cenex	Kr-Ce	Po-Ce	Conoco	Kr-Co	Po-Co
	Unmodified	Kraton	Polybilt	Unmodified	Kraton	Polybilt
	Cenex	Modified	Modified	Conoco	Modified	Modified
		Cenex	Cenex		Conoco	Conoco
Max. Marshall Stability at Percent	4.50	5.00	4.50	4.83	4.50	4.50
Max. Unit Weight at Percent	5.50	5.50	5.00	5.00	5.75	5.50
4 Percent Air Voids at Percent	4.78	4.63	4.63	4.55	4.53	4.53
Average Optimum Asphalt Content	4.93	5.04	4.71	4.79	4.93	4.84

Properties of the Mix at Optimum Asphalt Content

Marshall Stability in lbs.	4687.50	4316.00	4487.72	4195.65	4618.18	4354.55
Marshall Flow in 1/100 Inch.	14.00	16.15	14.43	12.10	14.44	13.71
Unit Weight in gm/cc	2.386	2.377	2.387	2.397	2.376	2.384
Unit Weight in Pcf	148.89	148.32	148.95	149.57	148.26	148.76
Percent Air Voids in Percent	3.79	2.86	3.70	3.00	2.83	3.06

improves the stability value.

Comparison of the Mix Properties for First Gradation Aggregates With and Without Selected Large Stone for Broken Faces.

The shape and texture, number of broken faces, of the large stone could be a major factor in the variation of the test properties of 6-inch specimens. The first set of first gradation large stone aggregate with unmodified and modified, Cenex and Conoco was carried out with 75 blows compaction. An identical series of tests of 6-inch specimens with first gradation aggregates was repeated; the only difference in this set of tests was the selection of large stone with at least two broken faces.

Figure M5 demonstrates the optimum asphalt content of the unmodified Cenex, Kr-Ce, Po-Ce, unmodified Conoco, Kr-Co, and Po-Co with and without selected large stone aggregates for at least two broken faces of large stone aggregates with 75 blow compaction. The optimum asphalt contents for the mix without selected large stone aggregates were high in all cases. They were between 4.87 and 5.41 percent; whereas, those of the mix with selected broken faced large stone aggregates were between 4.71 to 5.04 percent. The reduction in asphalt content for optimum asphalt content in percent were 0.48 for Cenex, 0.32 for Kr-Ce, 0.16 for Po-Ce, 0.47 for Conoco, 0.31 for Kr-Co and 0.55 for Po-Co. Although the asphalt contents were low for the 6-inch specimens with selected aggregate for broken faces, the stability values were found to be high as shown in Figure M6. However, the degree of improvements in stability in lbs. were different; for

# Opt. Asp. Content—First Gradation With And Without Selected Large Stone Agg.

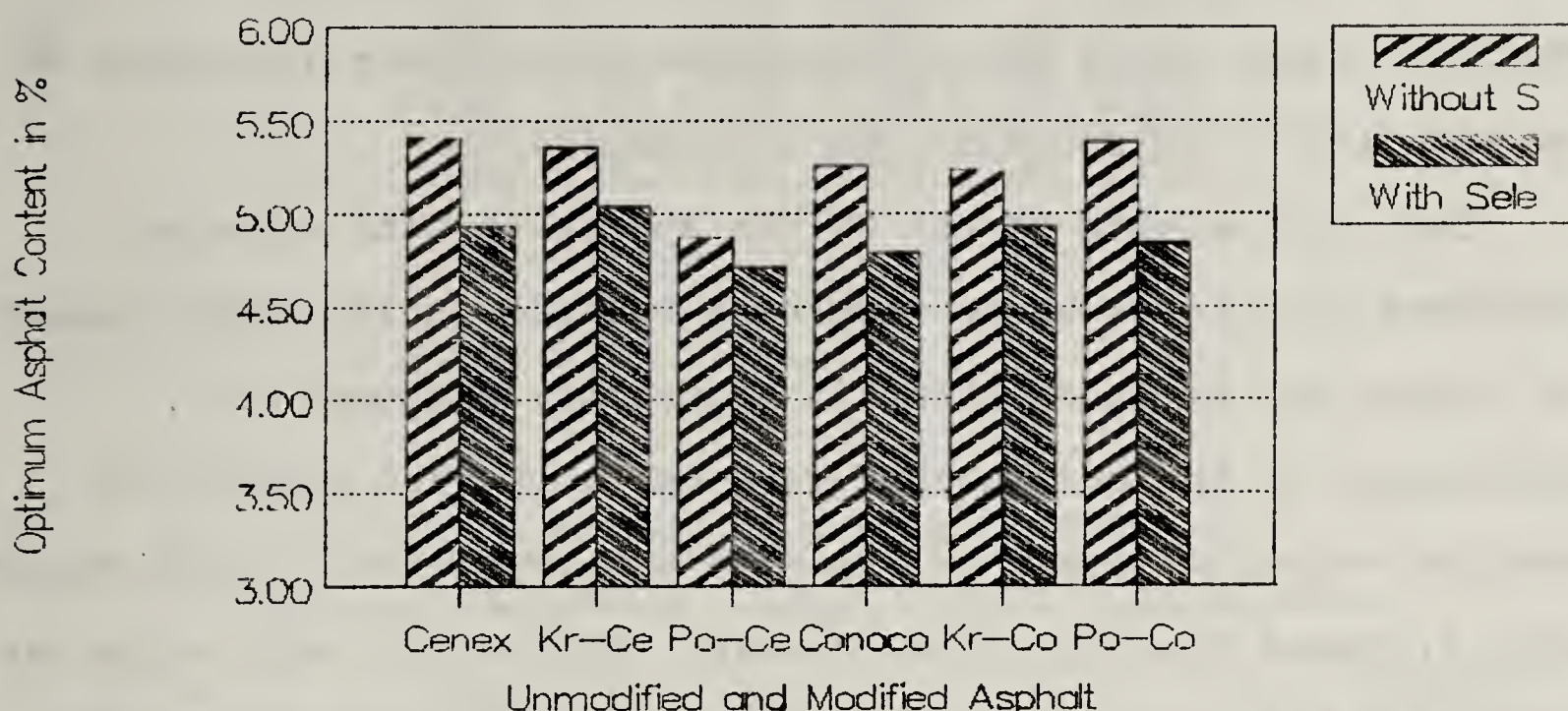


Figure M5. Optimum Asphalt Content for First Gradation with and without Selected Large Stone Aggregates.

# Marshall Stability—First Gradation With And Without Selected Large Stone Agg.

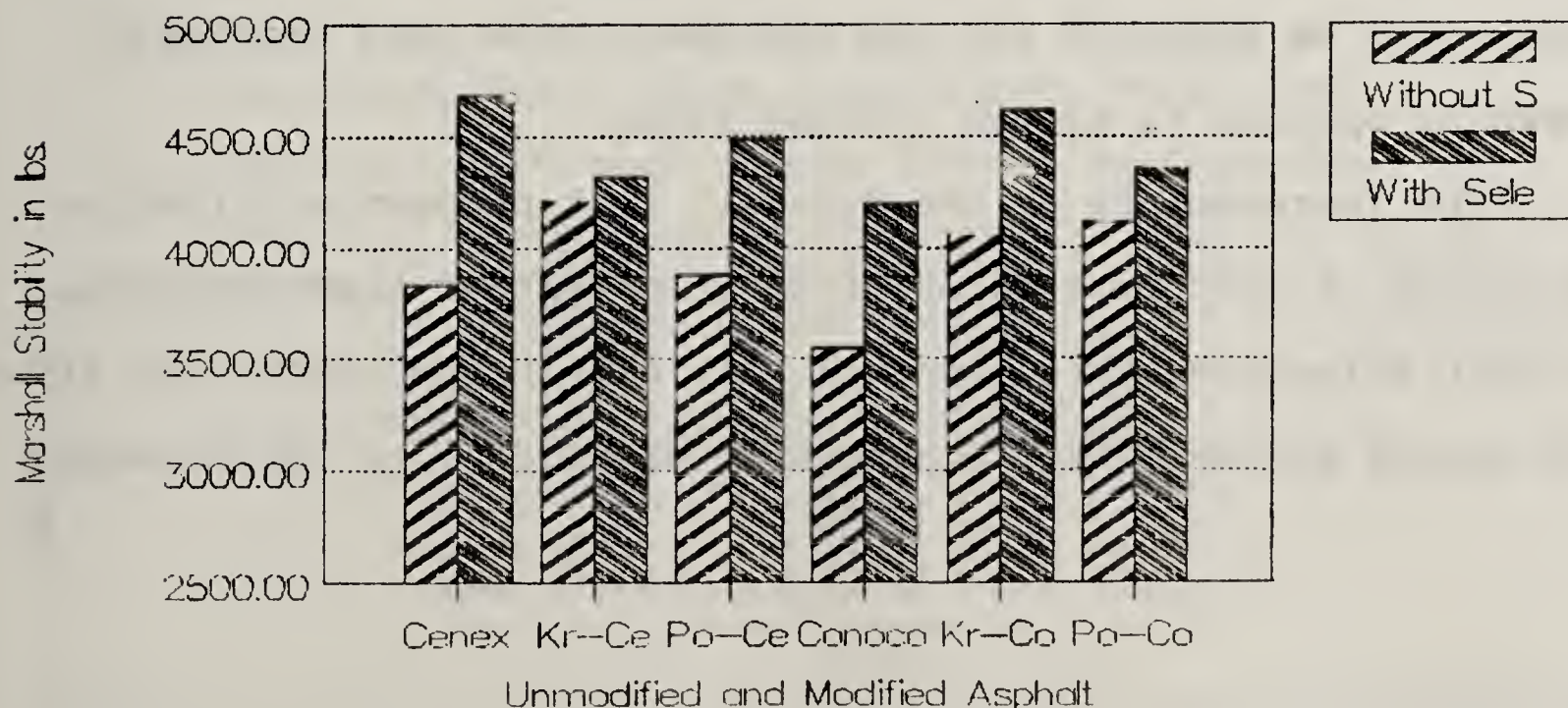


Figure M6. Stability for First Gradation with and without Selected Large Stone Aggregates.

Cenex, stability was increased by 863 as compared to 110 for Kr-Ce and 613 for Po-Ce, making the stability of unmodified Cenex higher than those of modified Cenex. Similarly, improvements for unmodified and modified Conoco were 655 for Conoco, 564 for Kr-Co, and 243 for Po-Co. These improvements indicate that the fractured faced large stone aggregates have higher influence on the stability than modification of asphalt.

The unit weights of the 6-inch specimens with selected fractured face large stone were also reduced in all cases except for Conoco and Kr-Co as shown in Figure M7, although the differences in the unit weight were not much with respect to absolute value. As could be expected the reduction in unit weight could increase the air voids. However, the percent air voids was higher for the 6-inch specimens with selected large stone than those of specimens without selected large stone aggregates as shown in Figure M8. Again, increase in air voids for Cenex (1.24 percent) was higher than the rest of modified Cenex. From Figure M9, flow values of the 6-inch specimens with selected large stone aggregates were decreased compared to that of specimens without selected large stone aggregates in all cases except for Po-Ce. This could be expected for the specimens with more fractured faces as opposed to smooth rounded faces.

The improvements of the Marshall test properties with the selection of fractured faced large stone rather than specimens without selections were observed. All 6-inch specimens with first and second gradation aggregates were prepared with the selected

### Unit Weight—First Gradation With and Without Selected Large Stone Aggregates

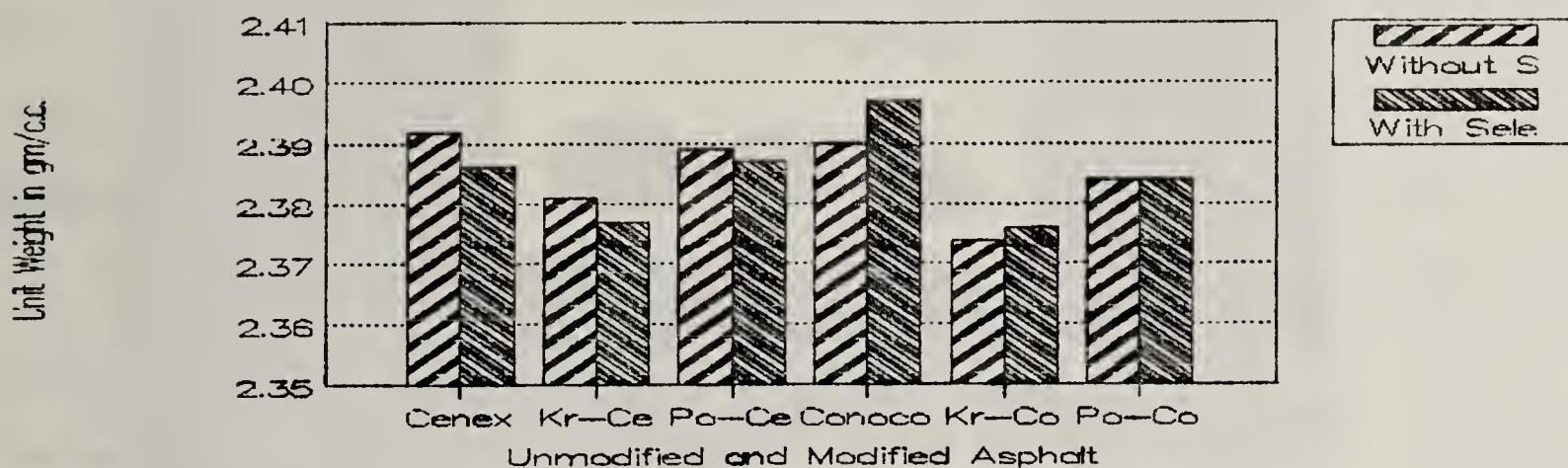


Figure M7. Unit Weight for First Gradation with and without Selected Large Stone Aggregates.

### Air Voids—First Gradation With and Without Selected Large Stone Aggregates



Figure M8. Air Voids for First Gradation with and without Selected Large Stone Aggregates.

### Marshall Flow—First Gradation With and Without Selected Large Stone Aggregates

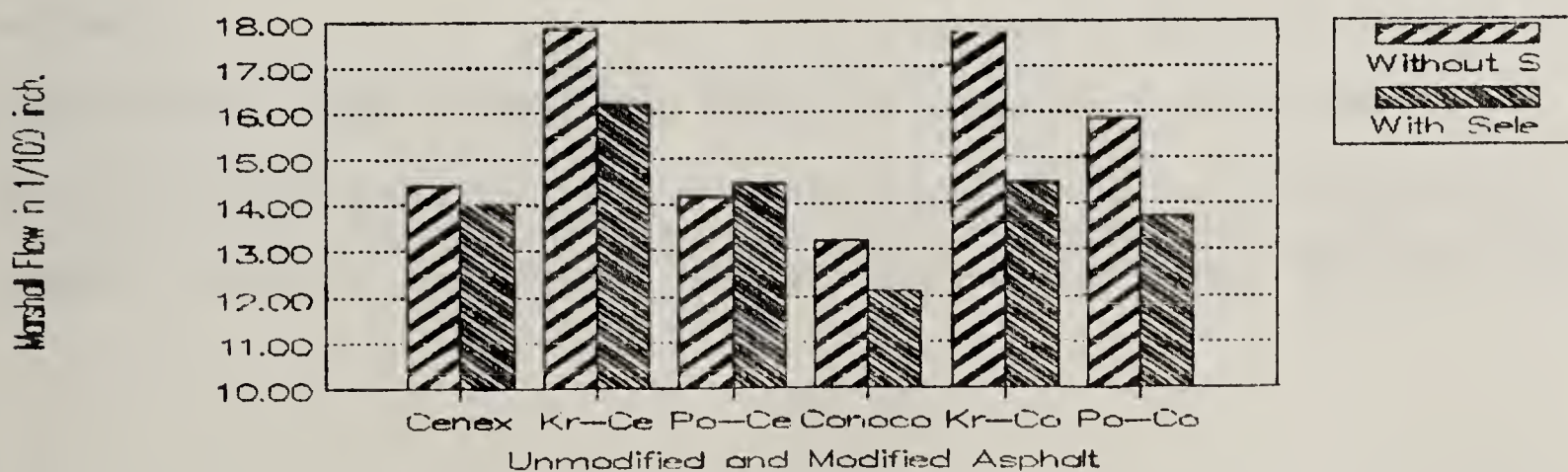


Figure M9. Flow for First Gradation with and without Selected Large Stone Aggregates.



Figure M10. Aggregates with Single and no Broken Faces, and Stripped Aggregates-Kraton Cenex Mix.

fractured face large stone with at least two broken faces. The picture of the rejected large stone aggregate is shown in Figure M10, along with a picture of stripped aggregate of Kraton modified Cenex sample.

#### Specimens with Selected Large Stone Aggregates, 112 Blows

Similarly, a randomized set of tests was conducted for first gradation aggregates with 112 blows compaction. The result for Cenex, Kraton and Polybilt modified Cenex are presented in Table M8. The tests were conducted with six asphalt contents (4, 4.5, 5, 5.5, 6, 6.5 percent) to observe the effect of large stone aggregates over a large range of asphalt contents. The standard deviation of the results was low. The maximum stability occurred at asphalt content between 4.5 and 5 percent. The stability values decreased with the increase of asphalt content beyond 4.5 and 5 percent in all cases. The stability value of Polybilt modified Cenex is highest, indicating the improvement of stability values by modification.

The results of the first gradation large stone aggregates with 112 blows compaction for modified and unmodified Conoco are presented in Table M9. The tests were conducted at five different asphalt contents (4, 4.5, 5, 5.5, and 6 percent). The highest stability values occurred at asphalt contents between 4 and 5 percent. The test properties curve for these data are shown in Appendix B. They showed the definite peak maximum values for stability and density, and a decreasing trend with increasing asphalt content for voids, and an increasing trend with

Table M8. Marshall Test Results-Cenex with Selected First Gradation Aggregates, 112 Blows.

Tests	Unmodified Cenex 120/150 - 112 Blow Compaction					
Asphalt Content	4.00%	4.50%	5.00%	5.50%	6.00%	6.50%
Mean Marshall Stability in lbs.	4455.30	4949.92	4585.33	4328.75	3885.83	3670.75
Standard Dev. Marshall Stability	205.00	164.87	296.44	221.15	336.17	501.16
Mean Marshall Flow in 1/100 inch.	11.00	13.33	15.00	15.67	16.33	18.00
Standard Deviation Marshall Flow	0.00	2.31	3.61	1.53	1.15	3.61
Mean Bulk Specific Gravity	2.360	2.389	2.403	2.402	2.395	2.388
Standard Deviation Bulk Sp. Gr.	0.008	0.004	0.016	0.011	0.007	0.002
Unit Weight in Pcf.	147.26	149.07	149.95	149.88	149.45	149.01
Mean Rice Specific Gravity	2.492	2.464	2.458	2.438	2.431	2.412
Standard Deviation Rice Sp. Gr.	0.017	0.014	0.006	0.006	0.013	0.014
Mean Percent Air Voids	5.27	3.06	2.62	1.47	1.48	0.96
Standard Deviation % Air Voids	0.37	0.52	0.06	0.37	0.24	0.59
VMA*	14.98	14.39	14.34	14.83	15.53	15.78
Tests	Kraton Modified Cenex - 112 Blow Compaction					
Mean Marshall Stability in lbs.	4341.00	4583.50	4646.30	3771.20	3536.00	3639.3
Standard Dev. Marshall Stability	181.2	97.20	150.70	853.00	365.30	167.5
Mean Marshall Flow in 1/100 inch.	13.67	15.00	15.33	18.00	20.00	22.3
Standard Deviation Marshall Flow	1.53	1.00	2.08	2.65	2.00	2.89
Mean Bulk Specific Gravity	2.342	2.363	2.380	2.371	2.377	2.375
Standard Deviation Bulk Sp. Gr.	0.014	0.006	0.005	0.014	0.014	0.005
Unit Weight in Pcf.	146.14	147.45	148.51	147.95	148.32	148.20
Mean Rice Specific Gravity	2.479	2.456	2.445	2.416	2.397	2.390
Standard Deviation Rice Sp. Gr.	0.006	0.002	0.006	0.015	0.015	0.006
Mean Percent Air Voids	5.52	3.79	2.67	1.88	0.81	0.61
Standard Deviation % Air Voids	0.47	0.25	0.16	0.24	0.24	0.218
VMA*	15.63	15.32	15.16	15.93	16.16	16.23
Tests	Polybilt Modified Cenex - 112 Blow Compaction					
Mean Marshall Stability in lbs.	4628.67	4774.75	5273.50	4549.17	4238.00	3363.75
Standard Dev. Marshall Stability	310.55	241.22	207.00	180.40	443.40	189.00
Mean Marshall Flow in 1/100 inch.	12.33	14.33	15.33	17.00	19.00	21.33
Standard Deviation Marshall Flow	2.52	1.15	1.53	1.00	2.67	1.15
Mean Bulk Specific Gravity	2.364	2.381	2.395	2.388	2.395	2.378
Standard Deviation Bulk Sp. Gr.	0.007	0.011	0.008	0.011	0.004	0.012
Unit Weight in Pcf.	147.51	148.57	149.45	149.01	149.45	148.39
Mean Rice Specific Gravity	2.488	2.461	2.454	2.432	2.416	2.403
Standard Deviation Rice Sp. Gr.	0.010	0.017	0.002	0.007	0.005	0.009
Mean Percent Air Voids	5.09	3.24	2.42	1.78	0.90	1.50
Standard Deviation % Air Voids	0.13	1.10	0.36	0.74	0.36	0.40
VMA*	16.18	16.02	15.53	15.33	15.53	16.13

\* VMA values are based on assumed bulk specific gravity of aggregate = 2.651

Table M9. Marshall Test Results-Conoco with Selected First Gradation Aggregates, 112 Bl s.

Tests	Unmodified Conoco 120/150 - 112 Blow Compaction				
Asphalt Content	4.00%	4.50%	5.00%	5.50%	6.00%
Mean Marshall Stability in lbs.	4434.33	4373.20	4969.67	4425.50	3568.25
Standard Dev. Marshall Stability	214.20	476.70	396.54	301.00	135.46
Mean Marshall Flow in 1/100 inch.	12.67	12.67	14.33	18.00	17.67
Standard Deviation Marshall Flow	1.53	2.08	1.53	2.65	2.08
Mean Bulk Specific Gravity	2.364	2.383	2.395	2.405	2.399
Standard Deviation Bulk Sp. Gr.	0.010	0.016	0.014	0.005	0.006
Unit Weight in Pcf.	147.51	148.70	149.45	150.07	149.70
Mean Rice Specific Gravity	2.495	2.479	2.461	2.440	2.429
Standard Deviation Rice Sp. Gr.	0.012	0.009	0.009	0.006	0.01
Mean Percent Air Voids	5.24	3.87	2.58	1.45	1.25
Standard Deviation % Air Voids	0.12	0.29	0.21	0.10	0.27
VMA*	14.84	14.60	14.63	14.72	14.48

Tests	Kraton Modified Conoco - 112 Blow Compaction				
Mean Marshall Stability in lbs.	4681.67	5155.08	4858.30	4745.50	4279.00
Standard Dev. Marshall Stability	271.97	314.56	662.70	449.80	94.00
Mean Marshall Flow in 1/100 inch.	12.00	16.00	15.33	18.00	20.33
Standard Deviation Marshall Flow	1.00	2.00	0.58	2.00	1.53
Mean Bulk Specific Gravity	2.361	2.377	2.394	2.385	2.383
Standard Deviation Bulk Sp. Gr.	0.003	0.015	0.006	0.011	0.004
Unit Weight in Pcf.	147.33	148.32	149.39	148.82	148.70
Mean Rice Specific Gravity	2.483	2.462	2.453	2.419	2.411
Standard Deviation Rice Sp. Gr.	0.004	0.013	0.008	0.009	0.006
Mean Percent Air Voids	4.91	3.47	2.38	1.38	1.16
Standard Deviation % Air Voids	0.24	0.71	0.41	0.29	0.37
VMA*	14.95	14.82	14.66	15.43	15.05

Tests	Polybilt Modified Conoco - 112 Blow Compaction				
Mean Marshall Stability in lbs.	5024.83	4929.00	4628.67	4602.20	4181.67
Standard Dev. Marshall Stability	297.80	191.10	441.31	307.10	772.60
Mean Marshall Flow in 1/100 inch.	12.33	13.33	16.00	16.00	20.67
Standard Deviation Marshall Flow	0.58	1.53	1.73	2.65	1.15
Mean Bulk Specific Gravity	2.370	2.382	2.387	2.394	2.388
Standard Deviation Bulk Sp. Gr.	0.004	0.015	0.009	0.007	0.008
Unit Weight in Pcf.	147.89	148.64	148.95	149.39	149.01
Mean Rice Specific Gravity	2.492	2.473	2.453	2.440	2.418
Standard Deviation Rice Sp. Gr.	0.006	0.002	0.006	0.008	0.008
Mean Percent Air Voids	4.88	3.69	2.68	1.86	1.21
Standard Deviation % Air Voids	0.19	0.54	0.19	0.06	0.58
VMA*	14.62	14.64	14.91	15.11	14.88

\* VMA values are based on assumed bulk specific gravity of aggregate = 2.651

increasing asphalt content for flow.

The optimum asphalt content for each of the modified and unmodified Conoco was computed from the peak values of stability and density and asphalt content at 4% air voids. The optimum asphalt content computation and corresponding parameter values are shown in Table M10. The optimum asphalt content occurred between 4.58 and 4.98. Stability values at optimum asphalt content were 4975.14 for Cenex, 4642.86 for Kr-Ce, 5181.82 for Po-Ce, 4966.67 for Conoco, 5133.33 for Kr-Co, and 4887.50 for Po-Co. Flow values at optimum asphalt content of modified Cenex increased while that of modified Conoco decreased. Air voids remained at around 3 percent.

#### Specimens with Selected Large Stones and Mineral Filler, 75 Blows

The Marshall mix design for the first gradation aggregates with mineral filler was conducted with 1.4 percent lime mineral filler added to the aggregate mix. The tests were conducted with 75 blows compaction at six different asphalt contents, to observe the effect of mineral filler for a large range of asphalt content. Moreover, the tests had to be conducted at 3.4 and 4 percent asphalt contents to obtain 4 percent air voids. The mean and standard deviation of three repetitions at each asphalt content are shown in Table M11 for both unmodified and modified Cenex.

The stability of unmodified Cenex and Polybilt modified Cenex were stable over a wide range of asphalt content. High stability was observed at an asphalt content of 4 percent for

Table M10. Optimum Asphalt Content-First Gradation Aggregates with Selected Large Stones.  
112 Blows Compaction, and Mix Properties at Optimum Asphalt Content.

Asphalt	Unmodified	Kraton	Polybilt	Unmodified	Kraton	Polybilt
	Cenex	Modified	Modified	Conoco	Modified	Modified
		Cenex	Cenex		Conoco	Conoco
	-----	-----	-----	-----	-----	-----
Max. Marshall Stability at Percent	4.50	5.00	5.00	5.00	4.50	4.00
Max. Unit Weight at Percent	5.00	5.00	5.00	5.50	5.00	5.50
4 Percent Air Voids at Percent	4.25	4.41	4.26	4.45	4.35	4.40
Average Optimum Asphalt Content	4.58	4.80	4.75	4.98	4.62	4.63

Properties of the Mix at Optimum Asphalt Content

Marshall Stability in lbs.	4957.14	4642.86	5181.82	4966.67	5133.33	4887.50
Marshall Flow in 1/100 Inch.	13.82	14.65	14.71	14.18	13.89	13.61
Unit Weight in gm/cc	2.393	2.378	2.391	2.398	2.386	2.384
Unit Weight in Pcf	149.32	148.39	149.20	149.64	148.89	148.76
Percent Air Voids in Percent	3.00	3.00	2.67	2.74	3.32	3.46

Table M11. Marshall Test Results-Cenex with First Gradation Aggregates and Mineral Filler, 75 Blows.

Tests	Unmodified Cenex 120/150 - 75 Blow Compaction					
Asphalt Content	3.50%	4.00%	4.50%	5.00%	5.50%	6.00%
Mean Marshall Stability in lbs.	4257.33	4493.17	4295.83	4255.92	3922.58	3373.25
Standard Dev. Marshall Stability	292.84	448.24	317.68	129.79	155.21	128.75
Mean Marshall Flow in 1/100 inch.	15.67	17.33	15.33	18.33	19.67	22.33
Standard Deviation Marshall Flow	2.08	0.58	2.31	2.15	1.55	1.53
Mean Bulk Specific Gravity	2.343	2.359	2.388	2.402	2.401	2.395
Standard Deviation Bulk Sp. Gr.	0.007	0.025	0.007	0.003	0.005	0.008
Unit Weight in Pcf.	146.20	147.20	149.01	149.88	149.82	149.45
Mean Rice Specific Gravity	2.495	2.464	2.472	2.455	2.437	2.423
Standard Deviation Rice Sp. Gr.	0.001	0.016	0.006	0.01	0.007	0.006
Mean Percent Air Voids	6.1	4.28	3.40	2.16	1.47	1.16
Standard Deviation % Air Voids	0.27	0.45	0.38	0.52	0.33	0.15
VMA*	16.92	16.35	15.33	14.83	14.86	15.08
Tests	Kraton Modified Cenex - 75 Blow Compaction					
Mean Marshall Stability in lbs.	3959.00	4553.83	4547.50	4314.83	4034.00	3516.67
Standard Dev. Marshall Stability	250.49	120.86	540.16	87.59	652.33	208.17
Mean Marshall Flow in 1/100 inch.	16.67	16.67	19.67	19.33	20.00	21.67
Standard Deviation Marshall Flow	1.15	2.08	2.52	1.15	2.00	1.53
Mean Bulk Specific Gravity	2.294	2.340	2.367	2.386	2.383	2.377
Standard Deviation Bulk Sp. Gr.	0.009	0.013	0.012	0.009	0.008	0.012
Unit Weight in Pcf.	143.15	146.02	147.70	148.89	148.70	148.32
Mean Rice Specific Gravity	2.473	2.445	2.459	2.440	2.419	2.398
Standard Deviation Rice Sp. Gr.	0.018	0.005	0.017	0.017	0.017	0.015
Mean Percent Air Voids	7.23	4.27	3.72	2.19	1.52	0.88
Standard Deviation % Air Voids	0.85	0.65	0.43	0.54	0.49	0.15
VMA*	17.79	16.59	15.18	14.95	15.50	51.43
Tests	Polybilt Modified Cenex - 75 Blow Compaction					
Mean Marshall Stability in lbs.	4718.75	4738.00	4532.00	4569.50	3726.17	3411.83
Standard Dev. Marshall Stability	185.72	425.46	136.26	255.48	179.44	412.52
Mean Marshall Flow in 1/100 inch.	14.67	16.67	19.00	20.33	19.67	21.00
Standard Deviation Marshall Flow	1.15	4.04	3.46	1.15	2.31	1.00
Mean Bulk Specific Gravity	2.320	2.361	2.389	2.406	2.400	2.389
Standard Deviation Bulk Sp. Gr.	0.016	0.019	0.004	0.004	0.004	0.004
Unit Weight in Pcf.	144.77	147.33	149.07	150.13	149.76	149.07
Mean Rice Specific Gravity	2.481	2.454	2.465	2.451	2.430	2.422
Standard Deviation Rice Sp. Gr.	0.008	0.014	0.017	0.011	0.008	0.004
Mean Percent Air Voids	6.47	3.81	3.10	1.86	1.25	1.36
Standard Deviation % Air Voids	0.52	0.34	0.52	0.50	0.42	0.25
VMA*	17.74	16.28	15.29	14.69	14.90	15.74

\* VMA values are based on assumed bulk specific gravity of aggregate = 2.651

both modified and unmodified Cenex. The 4 percent air voids were observed between asphalt contents of 3.5 and 4.5 percent.

The test results of Conoco and modified Conoco with the mineral filler are shown in Table M12. The tests with Conoco were also conducted over a wide range of 3.5 to 6 percent asphalt content.

The test properties curves were drawn as shown in Appendix B. The curves were smooth over the entire range. The optimum asphalt contents were computed from these curves. The computation of the optimum asphalt content and the test properties values at optimum asphalt content for all unmodified and modified Cenex and Conoco are shown in Table M13. The optimum asphalt content ranged from 4.31 to 4.5 percent. The stability at optimum asphalt content of Kraton and Polybilt modified Cenex (4548.57 and 4660.0) were larger than that of unmodified Cenex (4471.43). Similarly, the stability values of Kraton and Polybilt modified Conoco were 4781.82 and 4720.0 compared with that of unmodified Conoco 4292.31. The air voids at optimum asphalt content ranged from 2.88 to 3.63 and unit weight varied from 2.369 to 2.390 gm/c.c.. Judging from the stability values, the modified Cenex and Conoco were better than unmodified asphalt.

Comparison of Mix Properties of Conventional Asphalt and, First  
Gradation Large Stone Aggregates Mix with 75 and 112 Blows  
Compaction, and Mineral Filler

The comparison of mix properties of conventional 3/4-inch maximum size aggregate with 50 blows compaction and first large

Table M12. Marshall Test Results-Conoco with First Gradation Aggregates and Mineral Filler, 75 Blows.

Tests	Unmodified Conoco 120/150 - 75 Blow Compaction					
Asphalt Content	3.50%	4.00%	4.50%	5.00%	5.50%	6.00%
Mean Marshall Stability in lbs.	4471.92	4377.00	4153.85	4120.00	3332.20	3029.00
Standard Dev. Marshall Stability	351.50	236.00	126.19	136.26	296.00	106.41
Mean Marshall Flow in 1/100 inch.	16.00	16.00	14.67	16.00	20.33	21.00
Standard Deviation Marshall Flow	3.46	3.00	1.15	0.00	4.04	2.65
Mean Bulk Specific Gravity	2.342	2.372	2.391	2.401	2.405	2.381
Standard Deviation Bulk Sp. Gr.	0.007	0.004	0.004	0.007	0.007	0.011
Unit Weight in Pcf.	146.14	148.01	149.20	149.82	150.07	148.57
Mean Rice Specific Gravity	2.480	2.464	2.456	2.442	2.430	2.420
Standard Deviation Rice Sp. Gr.	0.008	0.019	0.002	0.004	0.009	0.001
Mean Percent Air Voids	5.59	3.73	2.65	1.66	1.02	1.61
Standard Deviation % Air Voids	1.18	0.56	0.85	0.25	0.12	0.46
VMA*	17.40	15.89	15.67	14.86	14.72	16.02

Tests	Kraton Modified Conoco - 75 Blow Compaction					
Mean Marshall Stability in lbs.	4333.33	4914.17	4396.29	4343.03	3825.25	3258.33
Standard Dev. Marshall Stability	236.29	296.83	257.57	252.81	447.40	434.69
Mean Marshall Flow in 1/100 inch.	17.33	17.00	14.33	18.33	20.33	24.33
Standard Deviation Marshall Flow	1.53	2.00	0.58	2.08	1.53	1.73
Mean Bulk Specific Gravity	2.364	2.351	2.364	2.390	2.389	2.389
Standard Deviation Bulk Sp. Gr.	0.008	0.015	0.008	0.006	0.010	0.011
Unit Weight in Pcf.	147.51	146.70	147.51	149.14	149.07	149.07
Mean Rice Specific Gravity	2.476	2.465	2.446	2.438	2.418	2.404
Standard Deviation Rice Sp. Gr.	0.017	0.001	0.010	0.010	0.006	0.005
Mean Percent Air Voids	6.27	4.61	3.35	1.99	1.21	0.65
Standard Deviation % Air Voids	0.83	0.86	0.53	0.17	0.31	0.46
VMA*	15.28	16.19	15.28	14.80	15.29	15.74

Tests	Polybilt Modified Conoco - 75 Blow Compaction					
Mean Marshall Stability in lbs.	4485.00	5028.33	4534.92	4253.50	4053.22	3262.97
Standard Dev. Marshall Stability	186.20	348.80	89.27	309.68	110.39	227.80
Mean Marshall Flow in 1/100 inch.	18.33	14.33	15.33	16.33	20.00	23.00
Standard Deviation Marshall Flow	4.04	0.58	1.53	0.58	1.73	2.65
Mean Bulk Specific Gravity	2.339	2.377	2.383	2.397	2.395	2.389
Standard Deviation Bulk Sp. Gr.	0.010	0.009	0.006	0.005	0.005	0.012
Unit Weight in Pcf.	145.95	148.32	148.70	149.57	149.45	149.07
Mean Rice Specific Gravity	2.484	2.475	2.459	2.442	2.425	2.416
Standard Deviation Rice Sp. Gr.	0.022	0.011	0.008	0.002	0.002	0.008
Mean Percent Air Voids	5.84	3.98	3.10	1.83	1.21	1.13
Standard Deviation % Air Voids	0.80	0.69	0.50	0.25	0.21	0.58
VMA*	16.18	15.27	14.60	14.55	15.08	15.74

\* VMA values are based on assumed bulk specific gravity of aggregate = 2.651

1990 Asphalt

Table M13. Optimum Asphalt Content-First Gradation Aggregates with Selected Large Stones and Mineral Filler, 75 Blows, and Mix properties at Optimum Asphalt Content.

Asphalt	Unmodified	Kraton	Polybilt	Unmodified	Kraton	Polybilt
	Cenex	Modified	Modified	Conoco	Modified	Modified
		Cenex	Cenex		Conoco	Conoco
	-----	-----	-----	-----	-----	-----
Max. Marshall Stability at Percent	4.00	4.25	4.00	3.50	4.00	4.00
Max. Unit Weight at Percent	5.00	5.00	5.00	5.50	5.00	5.00
4 Percent Air Voids at Percent	4.17	4.24	3.95	3.93	4.21	3.97
Average Optimum Asphalt Content	4.39	4.50	4.32	4.31	4.40	4.32

Properties of the Mix at Optimum Asphalt Content

Marshall Stability in lbs.	4471.43	4548.57	4660.00	4292.31	4781.82	4720.00
Marshall Flow in 1/100 Inch.	15.11	17.86	18.36	14.64	14.86	14.75
Unit Weight in gm/cc	2.390	2.369	2.382	2.384	2.373	2.390
Unit Weight in Pcf	149.14	147.83	148.64	148.76	148.08	149.14
Percent Air Voids in Percent	3.63	3.29	2.88	2.95	3.50	3.06

stone aggregate gradations with 75 and 112 blows and mineral filler with 75 blows is demonstrated in the form of a bar chart. Figure M11 demonstrates the optimum asphalt content of the unmodified Cenex, Kraton modified Cenex (Kr-Ce), Polybilt modified Cenex (Po-Ce), Conoco, Kraton modified Conoco (Kr-Co), and Polybilt modified Conoco (Po-Co) mixes with conventional 3/4-inch maximum size with 75 blows compaction and large stone 1 1/2-inch maximum size with 75 and 112 blows compaction and mineral filler with 75 blows compaction. The optimum asphalt content for the conventional mix was in the range of 5.5 to 6 percent, whereas the asphalt contents of large stone mix with comparable compaction of 75 blows reduced to 4.5 to 5 percent, that is the reduction of about one percent. The optimum asphalt content reduced progressively in the order of 75 and 112 and with mineral filler with 75 blows compaction. The increase of compaction from 75 to 112 blows the asphalt content was reduced by 0.25 percent except for Polybilt modified Cenex and unmodified Conoco. The addition of mineral filler reduced the optimum asphalt content as in the case of conventional asphalt mix. The reduction of optimum asphalt content due to the addition of mineral filler in the specimens with same number of blows that is, 75 blows, was remarkable; the reduction in percent was 0.54 for Cenex; 0.54 for Kr-Ce, 0.39 for Po-Ce, 0.48 for Conoco, 0.53 for Kr-Co, and 0.52 for Po-Co. The comparison of stability values of the above mixes is shown in Figure M12. The apparent stability improvement of the large stone mixes were remarkable. The apparent improvement of

## Optimum Asphalt Content-4" Mold 50 Blow

I Grad. 75, 112 Blow & Mineral Filler.

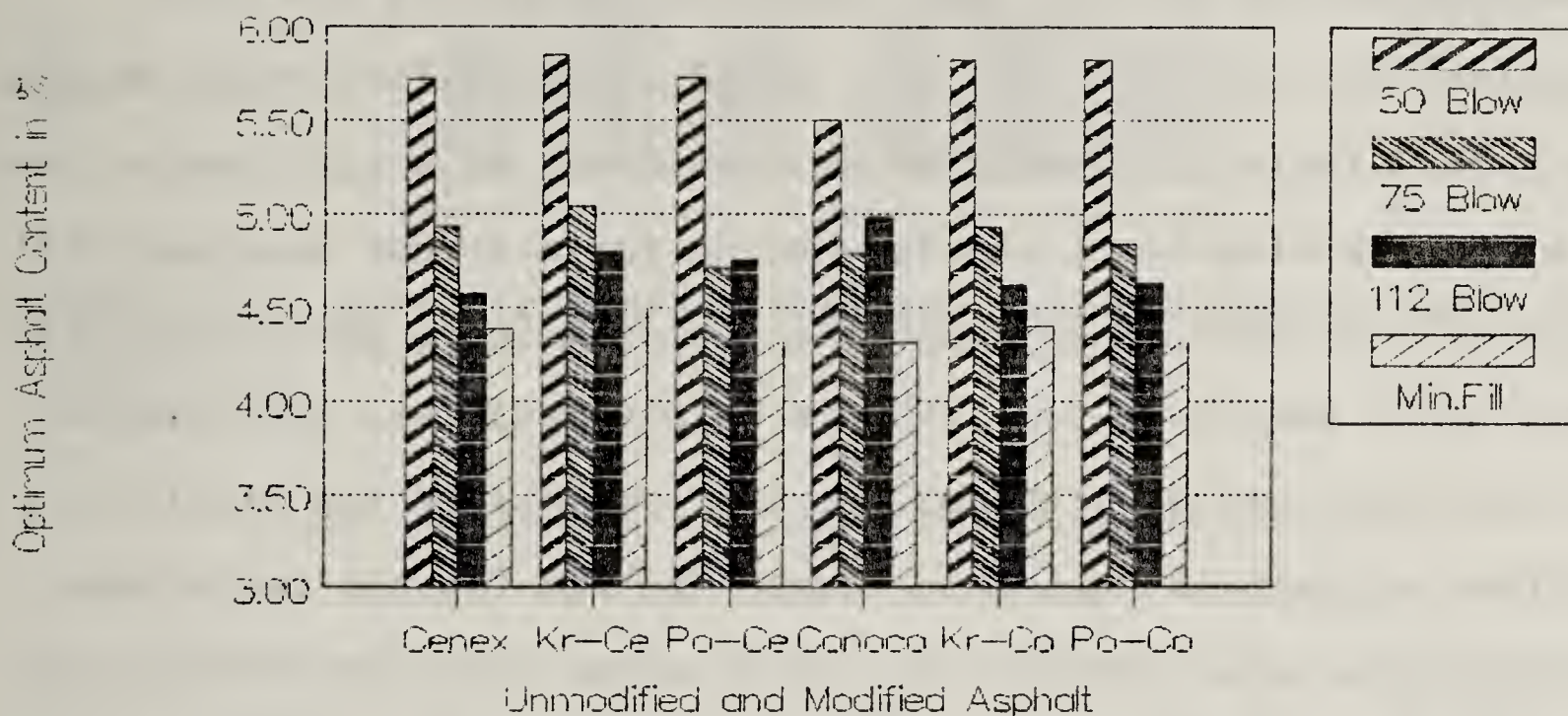


Figure M11. Optimum Asphalt Content for Conventional and First Gradation Large Stone Aggregates Mix With and Without Mineral Filler, at 75 and 112 Blows Compactions.

## Marshall Stability for 4" Mold 50 Blow

I-6" Mold 75, 112 Blow & Mineral Filler

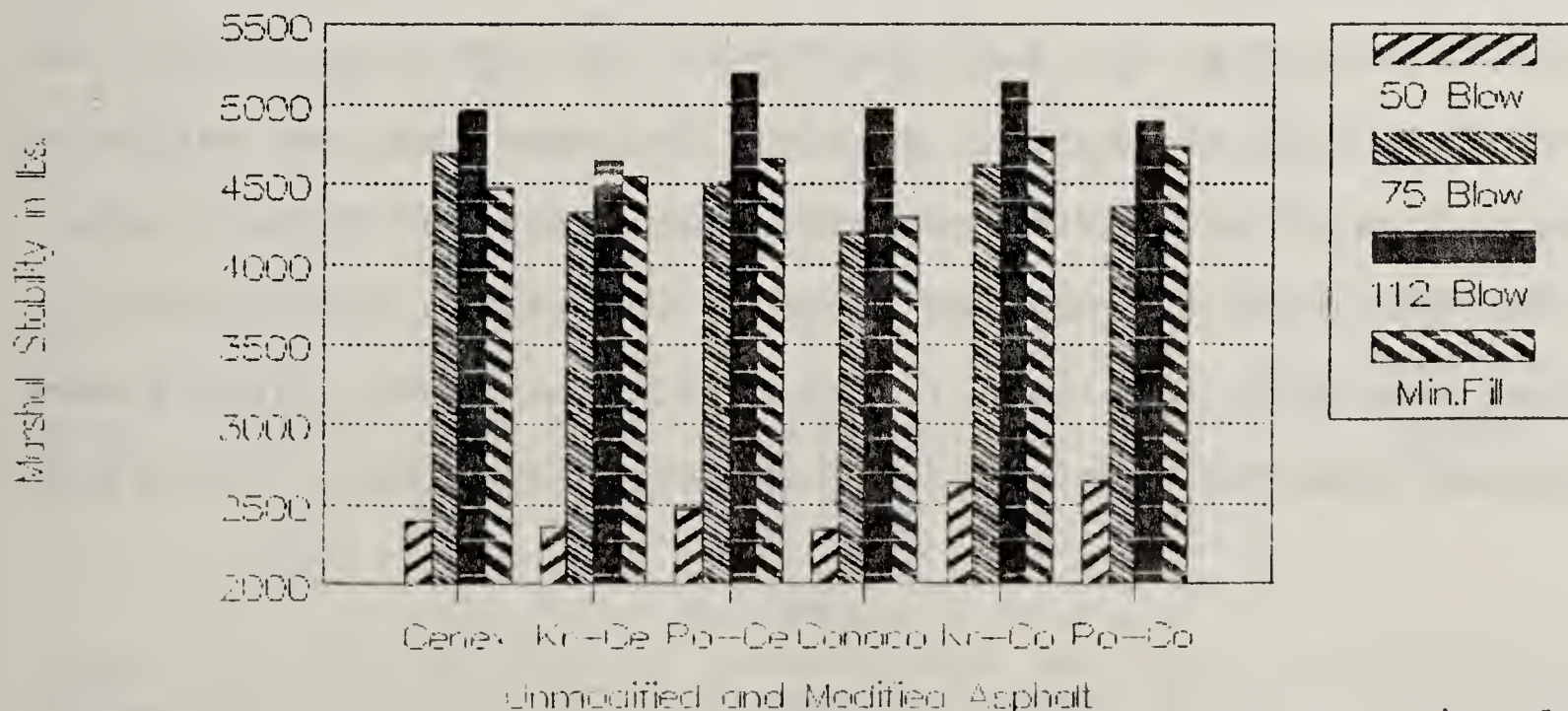


Figure M12. Stability for Conventional and First Gradation Large Stone Aggregates Mix With and Without Mineral Filler, 75, 112 Blows

the stability was doubled. The stability of conventional mix was in the 2300 to 2600 lbs. range, whereas the stability of comparable 75 blows large stone mix ranged from 4195 to 4618.

On the basis of unit stress, the total load on a 6-inch specimen should be 2.25 times the load applied to a 4-inch specimen for the same mix. This means the stability ratio should be 2.25. Similarly, when flow is considered on a unit basis (inch per inch of diameter), the flow value for a 6-inch specimen will be 1.5 times that of a 4-inch diameter specimen. This means the flow ratio should be 1.5.(4) This relationship was not observed in the exact ratio, although the improvements of the stability at optimum asphalt content were almost doubled for the comparison between the value obtained for large stone and conventional size aggregate mix. The stability ratios were: 1.96 for Cenex, 1.83 for Kr-Ce, 1.82 for Po-Ce, 1.79 for Conoco, 1.75 for Kr-Co, 1.65 for Po-Co. It should be noted that the ratio for the modified asphalt is less than that of unmodified asphalt, for both Cenex and Conoco. Similarly, the ratio of flow values of the 6-inch large stone aggregates and 4-inch conventional size aggregates at optimum asphalt content as shown in Figure M13 were 1.16 for Cenex, 1.12 for Kr-Ce, 1.07 for Po-Ce, 1.04 for Conoco, 0.95 for Kr-Co, and 0.90 for Po-Co. It should be noted that the ratios of flow values of unmodified asphalt, both Cenex and Conoco, were better than that of modified asphalt. The ratios of modified Conoco were even less than 1. The ratios for above analysis were obtained from the results of 4-inch molded specimens with 3/4-in

Marshall Flow - 4' Mold 50 Blow, I Grad  
6' Mold 75, 112 Blow & Mineral Filler.

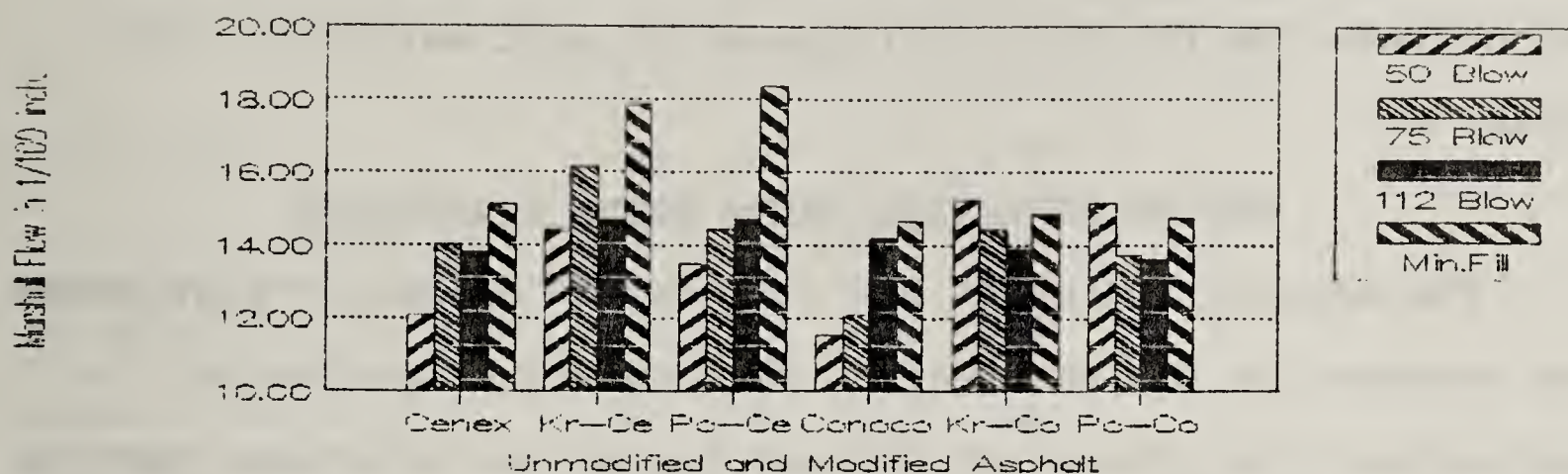


Figure M13. Flow for Conventional and First Gradation Large Stone Aggregates Mix With and Without Mineral Filler, at 75 & 112 Blows Compactions.

Unit Weight - 4' Mold 50 Blow, I Grad.  
6' Mold 75, 112 Blow & Mineral Filler.

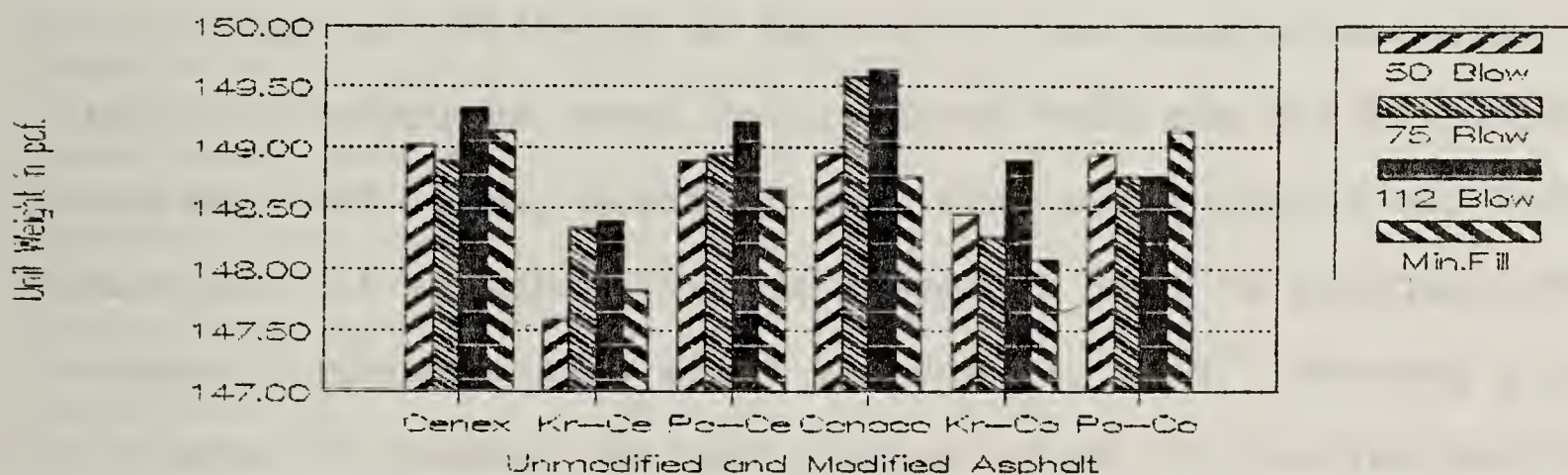


Figure M14. Unit Weight for Conventional and First Gradation Large Stone Aggregates Mix With and Without Mineral Filler, 75 & 112-Blow Compactions.

Air Voids - 4' Mold 50 Blow, I Grad.  
6' Mold 75, 112 Blow & Mineral Filler.

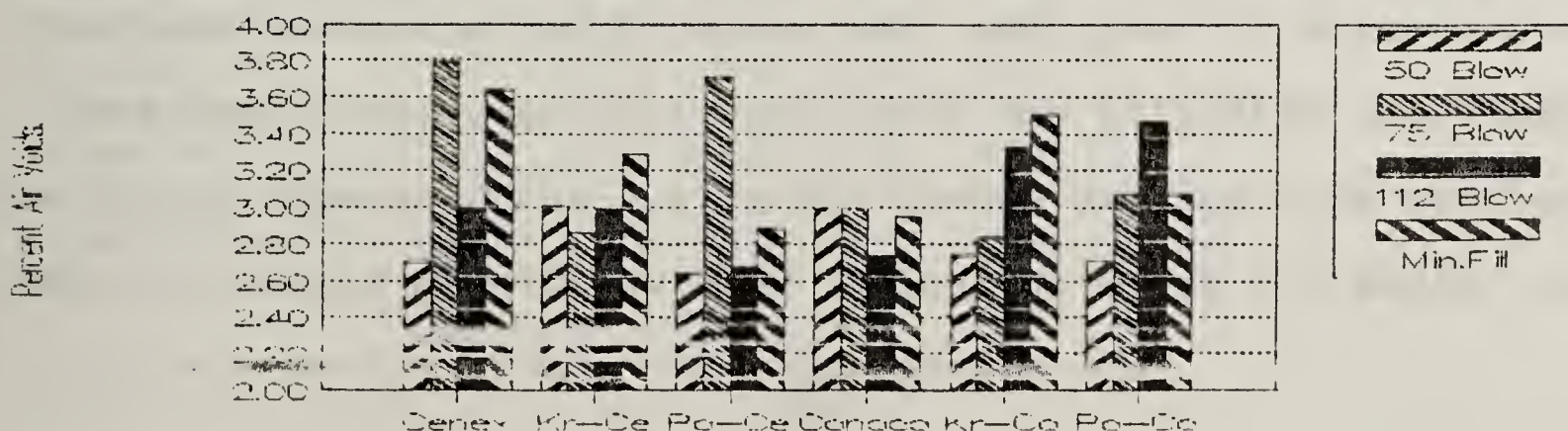


Figure M15. Air Voids for Conventional and First Gradation Large Stone Aggregates Mix With and Without Mineral Filler, 75 & 112-Blow Compactions.

inch maximum size aggregate and the 6-inch molded specimens with 1 1/2-inch maximum size aggregate. Figures M14 and M15 demonstrate the relative differences of unit weight and air voids.

### Second Gradation Large Stone Aggregates

The asphalt-aggregate mix with second gradation aggregates was prepared in the same way as with the first gradation aggregates. The process of preparation of the specimens and the Marshall testing were randomized according to the sampling scheme as before. This was done to minimize the effect of ignored variables. The Marshall specimens were prepared for a batch of modified and unmodified Cenex with 75 blows compaction. The range of mix temperatures was maintained at 284-296°F for both unmodified and modified Cenex. Large stone aggregates with at least two broken faces were used in these tests. The specimens were prepared at four different asphalt contents (3.5, 4, 4.5, and 5 percent). Four percent air voids were obtained in the samples between 3.5 and 4 percent asphalt content in both unmodified and modified Cenex.

### Specimens with Second Gradation Large Stone Aggregates, 75 Blows

The means and standard deviations of the Marshall tests for the specimen with second gradation aggregates with modified Cenex are presented in Table M14. The standard deviations of the test properties, stability and flow were relatively low except for stability at 4 percent Cenex, and at 3.5 and 5 percent Po-Ce, and flow values for Kr-Ce and Po-Ce. Unit weights in pounds per cubic

Table M14. Marshall Test Results-Cenex with Selected Second Gradation Aggregates, 75 Blows.

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 Tests Unmodified Cenex 120/150 Second Gradation - 75 Blow
 

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Asphalt Content	3.50%	4.00%	4.50%	5.00%
Mean Marshall Stability in lbs.	4528.33	4923.17	4596.17	3426.67
Standard Dev. Marshall Stability	167.10	83.25	457.06	243.64
Mean Marshall Flow in 1/100 inch.	12.00	13.00	13.67	16.00
Standard Deviation Marshall Flow	1.00	1.00	1.15	1.00
Mean Bulk Specific Gravity	2.383	2.416	2.414	2.414
Standard Deviation Bulk Sp. Gr.	0.011	0.007	0.003	0.006
Unit Weight in Pcf.	148.70	150.76	150.63	150.63
Mean Rice Specific Gravity	2.518	2.450	2.482	2.469
Standard Deviation Rice Sp. Gr.	0.008	0.003	0.004	0.009
Mean Percent Air Voids	5.36	3.34	2.73	2.22
Standard Deviation % Air Voids	0.72	0.17	0.28	0.18
VMA*	14.15	13.42	13.95	14.40

## Tests Kraton Modified Cenex Second Gradation - 75 Blow

Mean Marshall Stability in lbs.	4922.25	4469.75	5008.90	4403.42
Standard Dev. Marshall Stability	397.24	310.69	305.67	259.08
Mean Marshall Flow in 1/100 inch.	15.33	14.33	17.00	18.67
Standard Deviation Marshall Flow	2.52	1.53	2.65	3.06
Mean Bulk Specific Gravity	2.361	2.383	2.403	2.407
Standard Deviation Bulk Sp. Gr.	0.007	0.018	0.016	0.014
Unit Weight in Pcf.	147.33	148.70	149.95	150.20
Mean Rice Specific Gravity	2.517	2.493	2.484	2.458
Standard Deviation Rice Sp. Gr.	0.006	0.004	0.010	0.007
Mean Percent Air Voids	6.20	4.41	3.25	2.08
Standard Deviation % Air Voids	0.51	0.71	0.46	0.65
VMA*	14.95	14.60	14.34	14.65

## Tests Polybilt Modified Cenex Second Gradation - 75 Blow

Mean Marshall Stability in lbs.	4072.58	4587.08	4576.40	4087.50
Standard Dev. Marshall Stability	414.17	329.64	351.50	425.66
Mean Marshall Flow in 1/100 inch.	11.67	16.67	15.67	16.00
Standard Deviation Marshall Flow	2.08	6.35	2.08	2.00
Mean Bulk Specific Gravity	2.365	2.407	2.406	2.416
Standard Deviation Bulk Sp. Gr.	0.026	0.004	0.011	0.011
Unit Weight in Pcf.	147.58	150.20	150.13	150.76
Mean Rice Specific Gravity	2.520	2.499	2.481	2.461
Standard Deviation Rice Sp. Gr.	0.005	0.004	0.007	0.004
Mean Percent Air Voids	6.14	3.70	3.02	1.83
Standard Deviation % Air Voids	0.85	0.23	0.66	0.59
VMA*	14.80	13.74	14.23	14.33

\* VMA values are based on assumed bulk specific gravity of aggregate = 2.651

foot and VMA are also presented in Table M14. The unit weights of modified asphalt were low compared to that of unmodified Cenex. The maximum stability values were obtained at 4 and 4.5 percent asphalt contents. The stability of Kraton modified Cenex was highest at 4.5 percent asphalt content. The stability at 3.5 percent asphalt content was relatively higher than at 4 percent asphalt content, which might have resulted from aggregate-to-aggregate interlocking at low asphalt content. At 3.5 percent asphalt content, some of the large stones were not completely covered with asphalt, leaving white spots on the uncoated large stones.

The test results for second gradation large stone aggregates with modified and unmodified Conoco with 75 blows compaction are presented in Table M15. High stability values were observed at 3.5 percent asphalt content, which reduced with the increase in asphalt content, except for Polybilt modified Conoco. The unit weights increased with asphalt content in all cases. Standard deviations were low except for asphalt content of 3.5 percent for Kr-Co and 4 percent Po-Co. Four percent air voids were observed at asphalt content between 3.5 and 4 percent except for Kr-Co.

The test properties curves were drawn for both batches of Cenex and Conoco, unmodified and modified. The curves were smooth and are shown in Appendix C. The optimum asphalt contents were computed from these properties curves and are presented in Table M16. The optimum asphalt contents were obtained at levels between 4 and 4.5 percent. The values of test properties at optimum

Table M15. Marshall Test Results-Conoco with Selected Second Gradation Aggregates, 75 Blows.

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 Tests                                      Unmodified Conoco 120/150 Second Gradation - 75 Blow
 

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Asphalt Content	3.50%	4.00%	4.50%	5.00%
Mean Marshall Stability in lbs.	4708.27	4321.17	4259.83	3460.83
Standard Dev. Marshall Stability	40.51	252.71	281.35	167.24
Mean Marshall Flow in 1/100 inch.	13.00	17.00	15.67	14.66
Standard Deviation Marshall Flow	1.00	2.65	0.58	0.58
Mean Bulk Specific Gravity	2.377	2.399	2.399	2.412
Standard Deviation Bulk Sp. Gr.	0.010	0.021	0.013	0.012
Unit Weight in Pcf.	148.32	149.70	149.70	150.51
Mean Rice Specific Gravity	2.508	2.493	2.476	2.464
Standard Deviation Rice Sp. Gr.	0.002	0.012	0.010	0.006
Mean Percent Air Voids	5.20	4.08	3.12	2.10
Standard Deviation % Air Voids	0.34	0.90	0.94	0.53
VMA*	14.37	14.03	14.48	14.47

## Tests                                      Kraton Modified Conoco Second Gradation - 75 Blow

Mean Marshall Stability in lbs.	5065.92	4531.50	4548.75	4482.00
Standard Dev. Marshall Stability	531.72	95.55	295.02	90.00
Mean Marshall Flow in 1/100 inch.	13.33	14.67	17.00	20.00
Standard Deviation Marshall Flow	0.58	0.58	1.73	1.73
Mean Bulk Specific Gravity	2.373	2.378	2.404	2.416
Standard Deviation Bulk Sp. Gr.	0.007	0.012	0.005	0.009
Unit Weight in Pcf.	148.08	148.39	150.01	150.76
Mean Rice Specific Gravity	2.520	2.501	2.471	2.459
Standard Deviation Rice Sp. Gr.	0.012	0.006	0.002	0.008
Mean Percent Air Voids	5.81	4.92	2.71	1.75
Standard Deviation % Air Voids	0.33	0.27	0.14	0.07
VMA*	14.51	14.78	14.30	14.33

## Tests                                      Polybilt Modified Conoco Second Gradation - 75 Blow

Mean Marshall Stability in lbs.	4732.83	4969.50	4469.00	4334.53
Standard Dev. Marshall Stability	301.47	548.86	377.59	267.87
Mean Marshall Flow in 1/100 inch.	12.33	14.33	14.33	18.00
Standard Deviation Marshall Flow	0.58	1.53	0.58	1.73
Mean Bulk Specific Gravity	2.380	2.394	2.413	2.413
Standard Deviation Bulk Sp. Gr.	0.005	0.007	0.009	0.003
Unit Weight in Pcf.	148.51	149.39	150.57	150.57
Mean Rice Specific Gravity	2.519	2.492	2.471	2.462
Standard Deviation Rice Sp. Gr.	0.014	0.008	0.003	0.002
Mean Percent Air Voids	5.50	3.93	2.35	2.02
Standard Deviation % Air Voids	0.72	0.51	0.25	0.20
VMA*	14.26	14.21	13.98	14.44

\* VMA values are based on assumed bulk specific gravity of aggregate = 2.651

Table M16. Optimum Asphalt Content-Second Gradation Aggregates with Selected Large Stone.  
75 Blows Compaction, and Mix Properties at Optimum Asphalt Content.

Asphalt	Unmodified	Kraton	Polybilt	Unmodified	Kraton	Polybilt
	Cenex	Modified	Modified	Conoco	Modified	Modified
		Cenex	Cenex		Conoco	Conoco
Max. Marshall Stability at Percent	4.00	4.50	4.25	3.50	3.50	4.00
Max. Unit Weight at Percent	4.25	5.00	5.00	5.00	5.00	4.75
4 Percent Air Voids at Percent	3.75	4.14	3.88	4.04	4.14	3.94
Average Optimum Asphalt Content	4.00	4.55	4.38	4.18	4.21	4.23

Properties of the Mix at Optimum Asphalt Content

Marshall Stability in lbs.	4923.17	5000.00	4621.43	4400.00	4755.56	4916.07
Marshall Flow in 1/100 Inch.	12.78	17.10	15.09	14.78	15.64	15.91
Unit Weight in gm/cc	2.416	2.402	2.406	2.401	2.391	2.408
Unit Weight in Pcf	150.76	149.88	150.13	149.82	149.20	150.26
Percent Air Voids in Percent	3.34	2.88	2.88	3.75	3.78	3.33

asphalt content were computed from respective curves and are presented in the same Table M16. The Marshall stability of Kr-Ce (5000) was higher than those of Cenex (4923) and Po-Ce (4621). The flow of modified Cenex was higher than that of unmodified Cenex. The unit weight and percent air voids of Cenex were higher than those of modified Cenex.

The stability and flow values of modified Conoco were higher than those of unmodified Conoco. Modification of Conoco resulted in higher stability, but the degree of improvement was not remarkably high.

#### Specimens with Second Gradation Large Stone Aggregates with 112 Blows Compaction

The batch of specimens with second gradation aggregates prepared with 112 blows for Cenex, unmodified and modified, were tested for Marshall test properties. The means and standard deviations of the test properties were computed and are presented in Table M17. Standard deviations for the stability were low except for 3.5 percent Kr-Ce. Standard deviations of flow of Kr-Ce and Po-Ce at 3.5 and Po-Ce at 5 percent were high. High stabilities for Cenex and Po-Ce were obtained at 3.5 percent asphalt content but at 4 percent for Kr-Ce.

Similarly, the means and Standard deviations of the test properties were obtained for the Conoco, unmodified and modified, mixes. The results are presented in Table M18. The standard deviations of flow were generally high. The 4 percent air voids were obtained at 3.5 and 5 percent asphalt content.

Table M17. Marshall Test Results-Cenex with Selected Second Gradation Aggregates, 112 Blows.

Tests	Unmodified Cenex 120/150 Second Gradation - 112 Blow			
Asphalt Content	3.50%	4.00%	4.50%	5.00%
Mean Marshall Stability in lbs.	5749.75	4905.00	4805.10	4841.42
Standard Dev. Marshall Stability	401.42	196.50	103.17	122.88
Mean Marshall Flow in 1/100 inch.	12.00	12.33	12.67	14.33
Standard Deviation Marshall Flow	1.00	0.58	1.15	1.53
Mean Bulk Specific Gravity	2.401	2.407	2.425	2.428
Standard Deviation Bulk Sp. Gr.	0.006	0.005	0.010	0.007
Unit Weight in Pcf.	149.82	150.20	151.32	151.51
Mean Rice Specific Gravity	2.526	2.495	2.494	2.474
Standard Deviation Rice Sp. Gr.	0.009	0.004	0.011	0.008
Mean Percent Air Voids	4.95	3.51	2.79	1.89
Standard Deviation % Air Voids	0.21	0.06	0.65	0.44
VMA*	13.51	13.74	13.56	13.91
Tests	Kraton Modified Cenex Second Gradation - 112 Blow			
Mean Marshall Stability in lbs.	5423.67	5749.75	5123.00	4987.75
Standard Dev. Marshall Stability	509.3	374.60	237.60	419.50
Mean Marshall Flow in 1/100 inch.	15.00	14.00	18.33	18.67
Standard Deviation Marshall Flow	4.36	1.00	0.58	1.53
Mean Bulk Specific Gravity	2.377	2.411	2.416	2.417
Standard Deviation Bulk Sp. Gr.	0.002	0.004	0.003	0.005
Unit Weight in Pcf.	148.32	150.45	150.76	150.82
Mean Rice Specific Gravity	2.515	2.492	2.474	2.462
Standard Deviation Rice Sp. Gr.	0.009	0.009	0.006	0.003
Mean Percent Air Voids	5.49	3.35	2.35	1.80
Standard Deviation % Air Voids	0.26	0.41	0.16	0.10
VMA*	14.37	13.60	13.88	14.30
Tests	Polybilt Modified Cenex Second Gradation - 112 Blow			
Mean Marshall Stability in lbs.	5831.5	5631.70	4832.30	4496.25
Standard Dev. Marshall Stability	54.50	300.20	309.90	401.40
Mean Marshall Flow in 1/100 inch.	15.33	13.33	14.67	19.33
Standard Deviation Marshall Flow	4.04	0.58	0.58	4.04
Mean Bulk Specific Gravity	2.391	2.419	2.423	2.415
Standard Deviation Bulk Sp. Gr.	0.01	0.006	0.010	0.009
Unit Weight in Pcf.	149.20	150.95	151.20	150.70
Mean Rice Specific Gravity	2.520	2.494	2.475	2.462
Standard Deviation Rice Sp. Gr.	0.003	0.004	0.006	0.008
Mean Percent Air Voids	5.11	3.02	2.09	1.91
Standard Deviation % Air Voids	0.33	0.35	0.17	0.47
VMA*	13.87	13.31	13.63	14.37

\* VMA values are based on assumed bulk specific gravity of aggregate = 2.651

Table M18. Marshall Test Results-Conoco with Selected Second Gradation Aggregates, 112 Blows.

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 Tests Unmodified Conoco 120/150 Second Gradation - 112 Blow
 

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Asphalt Content	3.50%	4.00%	4.50%	5.00%
Mean Marshall Stability in lbs.	5313.75	5175.00	5014.00	4850.50
Standard Dev. Marshall Stability	668.04	332.56	196.50	536.76
Mean Marshall Flow in 1/100 inch.	15.67	16.00	15.67	14.67
Standard Deviation Marshall Flow	3.06	2.00	2.52	1.15
Mean Bulk Specific Gravity	2.392	2.410	2.424	2.423
Standard Deviation Bulk Sp. Gr.	0.003	0.019	0.003	0.011
Unit Weight in Pcf.	149.26	150.38	151.26	151.20
Mean Rice Specific Gravity	2.510	2.487	2.481	2.457
Standard Deviation Rice Sp. Gr.	0.006	0.005	0.009	0.004
Mean Percent Air Voids	4.70	3.10	2.32	1.37
Standard Deviation % Air Voids	0.20	0.55	0.43	0.29
VMA*	13.83	13.64	13.59	14.08

## Tests Kraton Modified Conoco Second Gradation - 112 Blow

Mean Marshall Stability in lbs.	4611.8	6092.42	5162.00	4973.17
Standard Dev. Marshall Stability	256.98	734.36	252.10	246.23
Mean Marshall Flow in 1/100 inch.	15.00	15.00	18.00	17.67
Standard Deviation Marshall Flow	1.00	2.00	2.00	2.52
Mean Bulk Specific Gravity	2.376	2.399	2.408	2.411
Standard Deviation Bulk Sp. Gr.	0.006	0.006	0.010	0.002
Unit Weight in Pcf.	148.26	149.70	150.26	150.45
Mean Rice Specific Gravity	2.502	2.480	2.468	2.446
Standard Deviation Rice Sp. Gr.	0.002	0.008	0.015	0.006
Mean Percent Air Voids	5.01	3.28	2.43	1.42
Standard Deviation % Air Voids	0.19	0.22	0.28	0.32
VMA*	14.41	14.03	14.16	14.51

## Tests Polybilt Modified Conoco Second Gradation - 112 Blow

Mean Marshall Stability in lbs.	5330.83	5377.30	5081.33	5141.17
Standard Dev. Marshall Stability	65.40	409.05	321.03	245.75
Mean Marshall Flow in 1/100 inch.	14.00	16.33	16.33	16.33
Standard Deviation Marshall Flow	2.00	2.30	0.58	1.53
Mean Bulk Specific Gravity	2.379	2.406	2.424	2.424
Standard Deviation Bulk Sp. Gr.	0.017	0.012	0.005	0.006
Unit Weight in Pcf.	148.45	150.13	151.26	151.26
Mean Rice Specific Gravity	2.513	2.485	2.469	2.455
Standard Deviation Rice Sp. Gr.	0.005	0.006	0.004	0.002
Mean Percent Air Voids	5.32	3.18	2.06	1.25
Standard Deviation % Air Voids	0.88	0.25	0.56	0.21
VMA*	14.30	13.78	13.59	14.05

\* VMA values are based on assumed bulk specific gravity of aggregate = 2.651

The smooth test properties curves were drawn and are presented in Appendix C. The optimum asphalt contents were computed from the test properties curve and are presented in Table M19. The optimum asphalt contents were between 3.90 and 4.24 percent. This was lower than those obtained for 75 blows compacted samples. The test properties values at optimum asphalt content were also shown in Table M19. The stability at optimum asphalt content of modified Kr-Ce (5527.27) and Po-Ce (5700) were higher than that obtained for Cenex (5150). Flow values were higher for modified Cenex, but unit weights were low.

Similarly, the stability of Kr-Co (5582) and Po-Co (5355) were higher compared with unmodified Conoco (5200). The flows at optimum asphalt content of modified Conoco were higher compared with unmodified Conoco. Percent air voids of unmodified Conoco were also higher compared to modified Conoco.

**Specimens with Second Gradation Large Stone Aggregates and Mineral Filler at 75 Blows Compaction**

The 6-inch Marshall specimens were prepared with second gradation large stone aggregates with 1.4 percent lime mineral filler. The tests were conducted at 4 different asphalt contents (3.5, 4, 4.5, and 5 percent) for both unmodified and modified asphalt. The mix temperatures for Cenex and Conoco were maintained as stated above. The whole processes of preparation of specimens and tests were randomized.

The test results are presented in Table M20. The stability at 3.5 percent asphalt content for unmodified Cenex and Po-Ce

Table M19. Optimum Asphalt Content-Second Gradation Aggregates with Selected Large Stones,  
112 Blows Compaction, and Mix Properties at Optimum Asphalt Content.

Asphalt	Unmodified	Kraton	Polybilt	Unmodified	Kraton	Polybilt
	Cenex	Modified	Modified	Conoco	Modified	Modified
		Cenex	Cenex		Conoco	Conoco
Max. Marshall Stability at Percent	3.50	4.00	3.50	3.50	4.00	4.00
Max. Unit Weight at Percent	5.00	5.00	4.50	4.75	5.00	4.75
4 Percent Air Voids at Percent	3.83	3.85	3.69	3.71	3.72	3.74
Average Optimum Asphalt Content	4.11	4.28	3.90	3.99	4.24	4.16

Properties of the Mix at Optimum Asphalt Content

Marshall Stability in lbs.	5150.00	5527.27	5700.00	5200.00	5581.82	5354.55
Marshall Flow in 1/100 Inch.	12.43	17.14	13.86	15.89	16.22	16.00
Unit Weight in gm/cc	2.417	2.414	2.416	2.411	2.403	2.416
Unit Weight in Pcf	150.82	150.63	150.76	150.45	149.95	150.76
Percent Air Voids in Percent	3.28	2.67	3.38	3.22	2.78	2.83

Table M20. Marshall Test Results-Cenex with Selected Second Gradation Aggregates and Mineral Filler. 75 Blows.

Tests	Unmodified Cenex 120/150 - 75 Blow Compaction			
Asphalt Content	3.50%	4.00%	4.50%	5.00%
Mean Marshall Stability in lbs.	4955.50	4913.25	5357.33	3962.75
Standard Dev. Marshall Stability	479.20	368.27	182.85	345.38
Mean Marshall Flow in 1/100 inch.	17.00	19.00	23.61	22.33
Standard Deviation Marshall Flow	1.00	1.00	2.08	4.90
Mean Bulk Specific Gravity	2.377	2.415	2.421	2.422
Standard Deviation Bulk Sp. Gr.	0.016	0.016	0.008	0.010
Unit Weight in Pcf.	148.32	150.70	151.07	151.13
Mean Rice Specific Gravity	2.480	2.477	2.459	2.458
Standard Deviation Rice Sp. Gr.	0.006	0.013	0.004	0.006
Mean Percent Air Voids	4.16	2.49	1.52	1.48
Standard Deviation % Air Voids	0.52	0.44	0.31	0.59
VMA*	14.37	13.46	13.70	14.12

Tests	Kraton Modified Cenex - 75 Blow Compaction			
Mean Marshall Stability in lbs.	4387.92	4479.58	4845.20	4063.33
Standard Dev. Marshall Stability	340.5	297.09	167.90	397.79
Mean Marshall Flow in 1/100 inch.	20.00	18.67	23.00	23.67
Standard Deviation Marshall Flow	1.73	2.08	1.73	4.04
Mean Bulk Specific Gravity	2.346	2.382	2.404	2.414
Standard Deviation Bulk Sp. Gr.	0.010	0.009	0.013	0.005
Unit Weight in Pcf.	146.39	148.64	150.01	150.63
Mean Rice Specific Gravity	2.490	2.471	2.466	2.436
Standard Deviation Rice Sp. Gr.	0.028	0.013	0.010	0.002
Mean Percent Air Voids	5.79	3.57	2.51	0.92
Standard Deviation % Air Voids	0.94	0.62	0.16	0.17
VMA*	15.49	14.64	14.30	14.40

Tests	Polybilt Modified Cenex - 75 Blow Compaction			
Mean Marshall Stability in lbs.	5033.92	5015.92	5074.30	3765.83
Standard Dev. Marshall Stability	148.59	326.15	58.00	419.76
Mean Marshall Flow in 1/100 inch.	16.33	20.33	19.33	18.67
Standard Deviation Marshall Flow	1.15	2.31	1.53	0.58
Mean Bulk Specific Gravity	2.372	2.404	2.406	2.418
Standard Deviation Bulk Sp. Gr.	0.013	0.009	0.010	0.002
Unit Weight in Pcf.	148.01	150.01	150.13	150.88
Mean Rice Specific Gravity	2.481	2.465	2.456	2.447
Standard Deviation Rice Sp. Gr.	0.030	0.008	0.007	0.008
Mean Percent Air Voids	4.39	2.49	2.04	1.09
Standard Deviation % Air Voids	0.65	0.35	0.56	0.39
VMA*	14.55	13.85	14.23	14.26

\* VMA values are based on assumed bulk specific gravity of aggregate = 2.651

were higher, although the maximum stability was obtained at 4.5 percent asphalt content. This may be due to the aggregate to aggregate interlocking at low asphalt content. The standard deviations of stabilities were low whereas they were high for flow in some cases. The standard deviations for unit weights for 3.5 and 4 percent Cenex, 4.5 percent Kr-Ce, and 3.5 percent Po-Ce were high.

The means and standard deviations of the test properties for Conoco and modified Conoco are presented in Table M21. The standard deviations of stability were low except for 5 percent Conoco, 4 percent Kr-Co, and 3.5 percent Po-Co. The maximum stability values were obtained at 3.5 percent asphalt content in all cases. The standard deviations of flow were high in most cases. The maximum unit weights were observed at 5 percent for Conoco and Kr-Co and 4.4 percent for Po-Co.

Smooth properties curves were drawn from these mean values for both Cenex and Conoco groups of tests. The test properties curves are presented in Appendix C. The optimum asphalt contents were computed from these curves. The results are shown in Table M22. The optimum asphalt content varied from 3.96 to 4.47 percent. These were higher than those obtained with 112 blows compacted specimens.

The test properties values at optimum asphalt content were computed from the curves and are shown in Table M22. The stability of the unmodified Cenex (5303) was higher than both modified Cenex, 4850 for Kr-Ce and 5100 for Po-Ce. The flow of

Table M21. Marshall Test Results-Conoco with Selected Second Gradation Aggregates and Mineral Filler. 75 Blows.

Tests	Unmodified Conoco 120/150 - 75 Blow Compaction			
Asphalt Content	3.50%	4.00%	4.50%	5.00%
Mean Marshall Stability in lbs.	5176.30	4452.00	4310.70	3657.00
Standard Dev. Marshall Stability	352.90	242.88	319.50	462.00
Mean Marshall Flow in 1/100 inch.	16.33	19.00	18.00	20.67
Standard Deviation Marshall Flow	0.58	4.58	2.65	2.31
Mean Bulk Specific Gravity	2.389	2.406	2.423	2.425
Standard Deviation Bulk Sp. Gr.	0.006	0.009	0.001	0.012
Unit Weight in Pcf.	149.07	150.13	151.20	151.32
Mean Rice Specific Gravity	2.485	2.481	2.465	2.459
Standard Deviation Rice Sp. Gr.	0.013	0.006	0.007	0.005
Mean Percent Air Voids	3.84	3.04	1.70	1.38
Standard Deviation % Air Voids	0.53	0.35	0.32	0.53
VMA*	13.94	13.78	13.63	14.01
Tests	Kraton Modified Conoco - 75 Blow Compaction			
Mean Marshall Stability in lbs.	5301.50	4633.58	4434.20	4106.00
Standard Dev. Marshall Stability	189.50	494.30	279.80	235.20
Mean Marshall Flow in 1/100 inch.	19.00	19.67	22.33	23.33
Standard Deviation Marshall Flow	2.65	2.08	2.08	4.16
Mean Bulk Specific Gravity	2.368	2.386	2.398	2.409
Standard Deviation Bulk Sp. Gr.	0.003	0.012	0.006	0.006
Unit Weight in Pcf.	147.76	148.89	149.64	150.32
Mean Rice Specific Gravity	2.489	2.477	2.451	2.440
Standard Deviation Rice Sp. Gr.	0.009	0.011	0.007	0.006
Mean Percent Air Voids	4.89	3.65	2.16	1.25
Standard Deviation % Air Voids	0.23	0.59	0.42	0.38
VMA*	14.69	14.50	14.52	14.58
Tests	Polybilt Modified Conoco - 75 Blow Compaction			
Mean Marshall Stability in lbs.	5245.9	5016.25	4363.67	4257.67
Standard Dev. Marshall Stability	513.00	482.11	110.32	186.13
Mean Marshall Flow in 1/100 inch.	16.67	18.33	18.00	21.00
Standard Deviation Marshall Flow	0.58	2.89	2.00	3.61
Mean Bulk Specific Gravity	2.386	2.395	2.420	2.416
Standard Deviation Bulk Sp. Gr.	0.009	0.011	0.006	0.003
Unit Weight in Pcf.	148.89	149.45	151.01	150.76
Mean Rice Specific Gravity	2.497	2.474	2.464	2.442
Standard Deviation Rice Sp. Gr.	0.010	0.003	0.004	0.009
Mean Percent Air Voids	4.46	3.21	1.76	1.08
Standard Deviation % Air Voids	0.25	0.33	0.31	0.31
VMA*	14.05	14.17	13.73	14.33

\* VMA values are based on assumed bulk specific gravity of aggregate = 2.651

1990 Asphalt

Table M22. Optimum Asphalt Content-Second Gradation Aggregates with Selected Large Stones and Mineral Filler, 75 Blows, and Mix properties at Optimum Asphalt Content.

Asphalt	Unmodified	Kraton	Polybilt	Unmodified	Kraton	Polybilt
	Cenex	Modified	Modified	Conoco	Modified	Modified
		Cenex	Cenex		Conoco	Conoco
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Max. Marshall Stability at Percent	4.50	4.50	4.50	3.50	3.50	3.50
Max. Unit Weight at Percent	5.00	5.00	5.00	5.00	5.00	4.69
4 Percent Air Voids at Percent	3.56	3.90	3.57	3.45	3.81	3.70
Average Optimum Asphalt Content	4.35	4.47	4.36	3.98	4.10	3.96

Properties of the Mix at Optimum Asphalt Content

Marshall Stability in lbs.	5303.45	4850.00	5100.00	4666.67	4600.00	5042.11
Marshall Flow in 1/100 Inch.	20.65	21.45	18.50	17.88	20.00	18.00
Unit Weight in gm/cc	2.418	2.402	2.410	2.409	2.389	2.406
Unit Weight in Pcf	150.88	149.88	150.38	150.32	149.07	150.13
Percent Air Voids in Percent	1.81	2.00	1.67	2.79	3.17	3.31

Kr-Ce was higher than unmodified Cenex but that of Po-Ce was lower. The unit weight of Cenex was higher than either modified Cenex. The percent air voids were low (1.67 to 3) compared to both 75 and 112 blows compacted specimens.

The stability of unmodified Conoco (4666.67) was higher than modified Kr-Co (4600) by marginal value, but lower than Po-Co (5042). The flow for modified Conoco was higher than that of unmodified Conoco. Unit weight of unmodified Conoco was higher than that modified Conoco. The percent air voids of unmodified Conoco was lower than unmodified Conoco.

Comparison of Mix Properties for Conventional Asphalt Mix with 50 Blows, and Second Gradation Large Stone Aggregates Mix with 75 and 112 Blows, and Mineral Filler, 75 Blows

The comparison of the optimum asphalt content and mix properties at the level of asphalt content for 4-inch specimens with 3/4-inch maximum size gradation, large stone aggregates with 75 and 112 blows, and mineral filler are illustrated in the bar charts.

The purpose of this comparison was to observe the degree of improvement of mix properties of the second gradation aggregate specimen, with different compaction and mineral filler, with conventional 3/4-inch maximum size aggregate with 50 blow compaction. The optimum asphalt contents were reduced in the 6-inch specimens with large stone aggregates in all cases (75, 112 and mineral filler) from a range of 4 to 4.5 percent to about 5.5 percent for 4-inch specimens as shown in Figure M16. The asphalt

Opt. Asp. Content-4' Mold 50 Blow II Gra

6' Mold 75, 112 Blow & Mineral Filler.

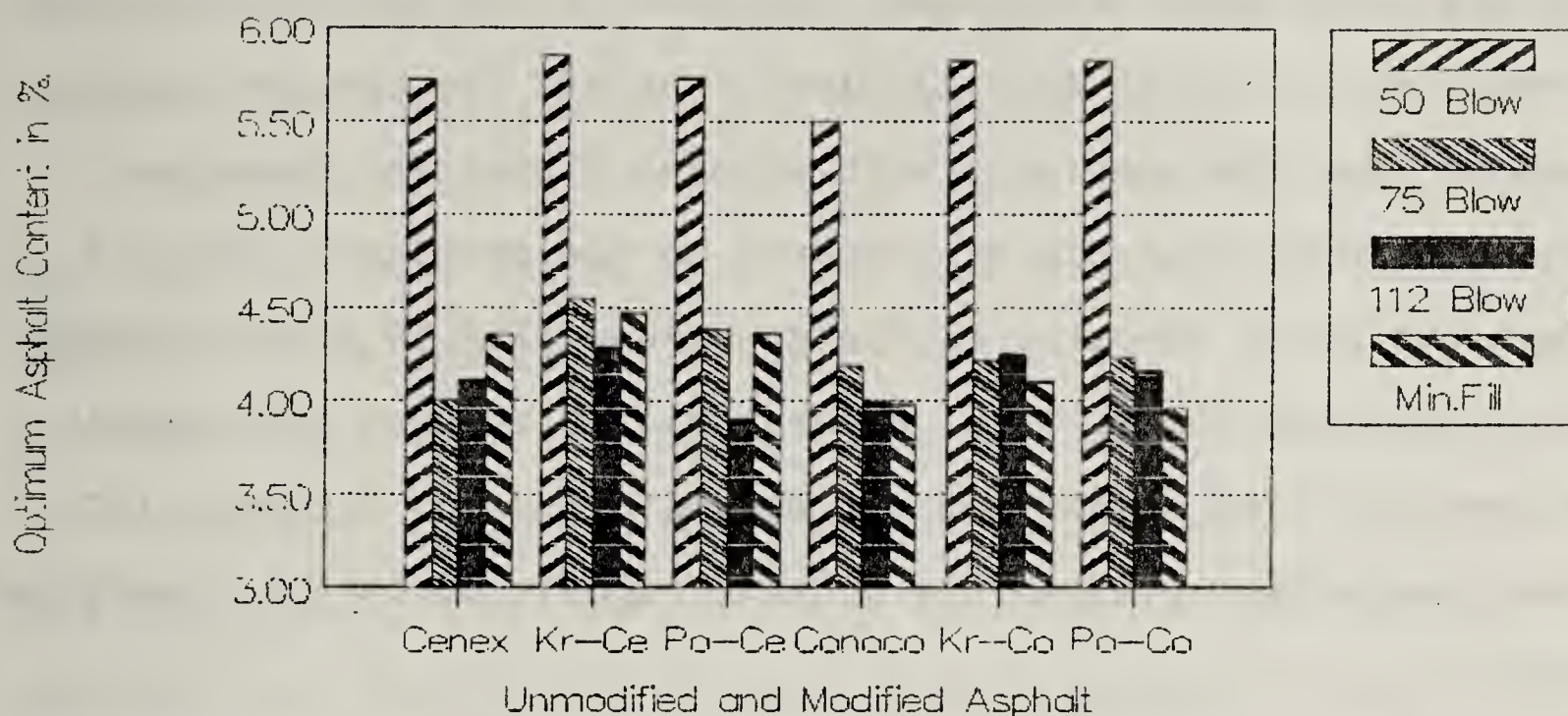


Figure M16. Optimum Asphalt Content for Conventional and Second Large Stone Gradation Aggregates Mix With and Without Mineral Filler, at 75 and 112 Blows Compactions.

Stability - 4' Mold 50 Blow, II Gra.Agg

6' Mold 75, 112 Blow & Mineral Filler.

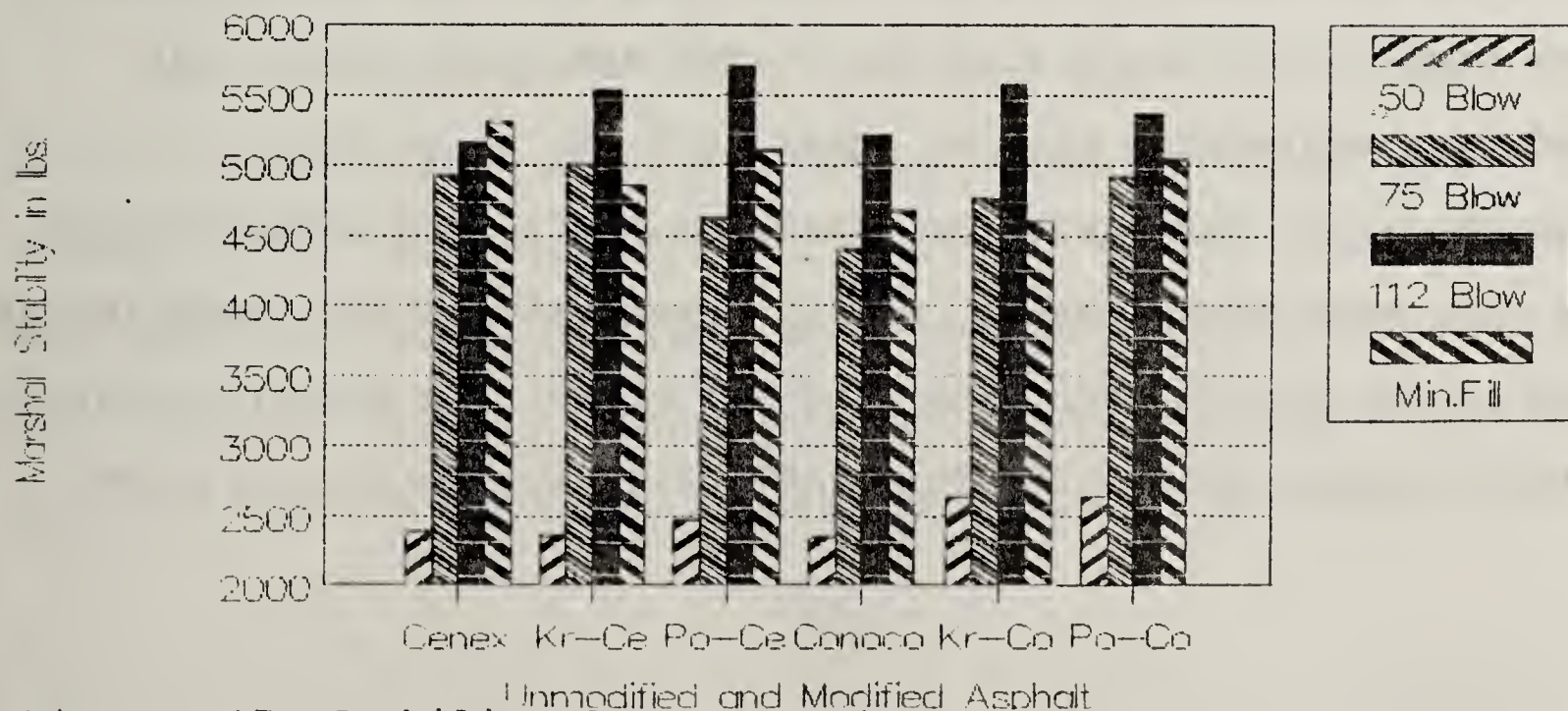


Figure M17. Stability for Conventional and Second Gradation Large Stone Aggregates Mix With and Without Mineral Filler, 75 & 112-Blow

contents for 6-inch specimens with 112 blows were lower than that of 75 blows specimens in all cases, except for Cenex and Kr-Ce, although the differences were not significant. The optimum asphalt content for the specimens with mineral filler for Conoco and modified Conoco were lower compared to the specimen without mineral filler at 75 and 112 blows. Whereas the optimum asphalt content for the specimens with mineral filler for Cenex and modified Cenex were higher compared to the specimens with 112 blows but lower compared to the specimens with 75 blows, except for unmodified Cenex. Thus, mineral filler reduced the asphalt content most for unmodified and modified Conoco; whereas, 112 blows compaction reduced the optimum asphalt content for modified Cenex.

The stability values of the 6-inch specimens with second gradation aggregates (with 75, 112 blows, and mineral filler) were about twice those of 4-inch specimens with conventional aggregates as shown in Figure M17. The ratio of stability values of 6-inch specimens with 75 blows to those of 4-inch specimens with 50 blows were 2.06 for Cenex, 2.12 for Kr-Ce, 1.87 for Po-Ce, 1.88 for Conoco, 1.18 for Kr-Co, and 1.86 for Po-Co. They were higher than the ratios for 6-inch specimens with first gradation aggregates but not equal to 2.25, as expected theoretically. The ratio for Cenex and Kr-Ce were higher than 2, the rest were lower than 2. Similar observations were made in the case of the 6-inch specimens with 112 blows. The stability ratios were 2.16 for Cenex, 2.35 for Kr-Ce, 2.31 for Po-Ce, 2.22 for

Conoco, 2.12 for Kr-Co, and 2.03 for Po-Co. The ratios were higher than those with 75 blows compaction, but high energy was spent with 112 blows compaction. Stability values of 6-inch specimens with mineral filler were in between 75 and 112 blows compaction without mineral filler; the ratio would be in between the above two ratios, except for unmodified Cenex.

Similarly, Figure M18 shows the differences in flow values. The ratios of flow values of 6-inch specimens with 75 blows to those of 4-inch specimens were 1.06 for Cenex, 1.19 for Kr-Ce, 1.12 for Po-Ce, 1.28 for Conoco, 1.03 for Kr-Co, and 1.05 for Po-Co. The highest ratio was obtained for Conoco, but all ratios were less than 1.5 as theoretically anticipated. Also it could be seen that the flow values of the 6-inch specimens of second gradation aggregates with mineral filler were distinctly higher than both 75 and 112 blows compacted specimens. They were in the range of 18 to 21, while those of 112 blows compaction were in the range of 12 to 17 and 75 blows specimens were in the range of 13 to 17. Flows of Cenex and modified Cenex at 75 blows were higher than those of 112 blows, while the reverse trend was seen for Conoco and modified Conoco.

The unit weights of 4-inch specimens were in the range of 147.5 to 149.61 pcf, whereas those of 6-inch specimens with 75 blows were in the range of 149.2 to 150.67 as seen from Figure M19. The large stone specimens were heavier than the conventional mix. The unit weight of 112 blows compacted specimens were higher than the rest in all cases except for Cenex; it was lower than

Flow - 4' Mold 50 Blow, II Grad. Agg.  
6' Mold 75, 112 Blow & Mineral Filler.

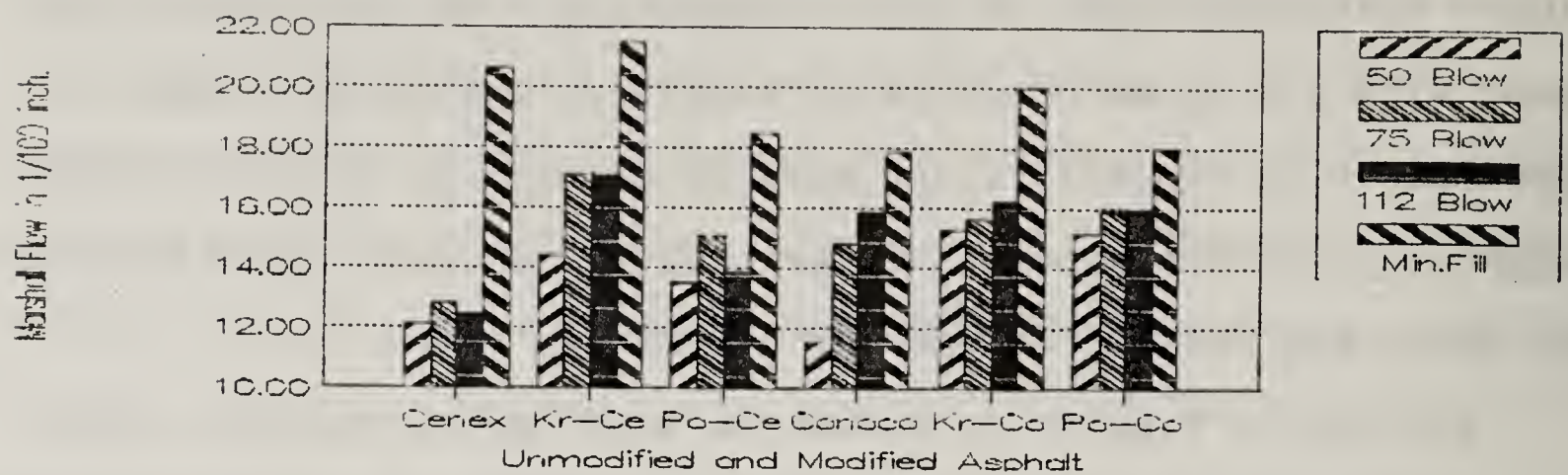


Figure M18. Flow for Conventional and Second Gradation Large Stone Aggregates Mix With and Without Mineral Filler, at 75 and 112 Blows Compactions.

Unit Weight - 4' Mold 50 Blow, II G. A.  
6' Mold 75, 112 Blow & Mineral Filler.

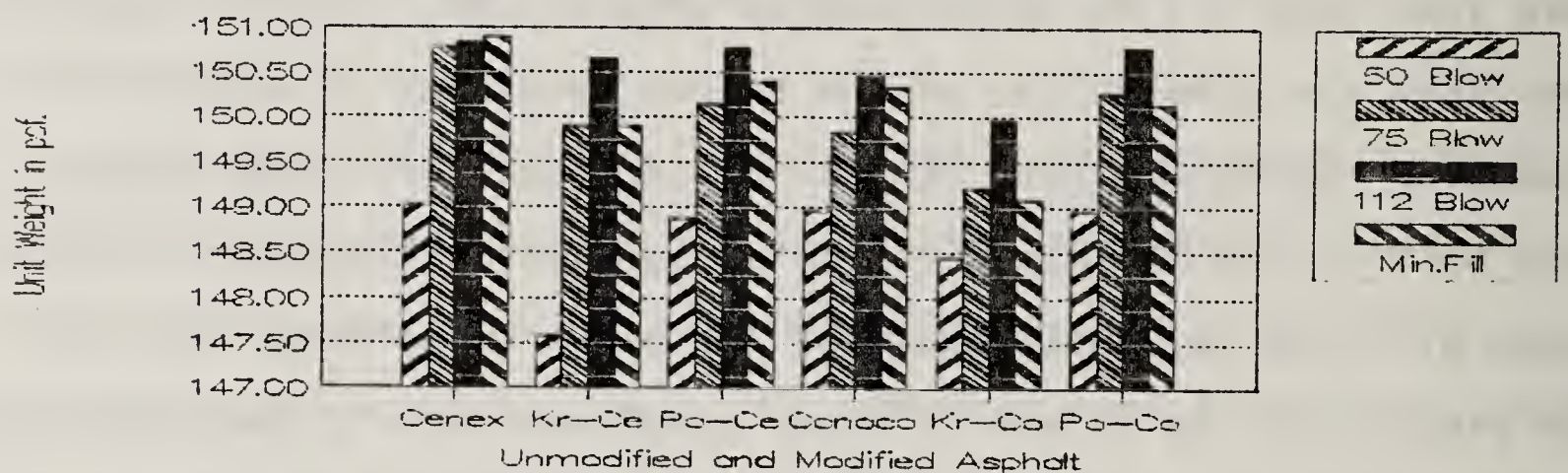


Figure M19. Unit Weight for Conventional and Second Gradation Large Stone Aggregates Mix With and Without Mineral Filler, 75 & 112-Blow Compactions.

Air Voids - 4' Mold 50 Blow, II Gra. Agg.  
6' Mold 75, 112 Blow & Mineral Filler.

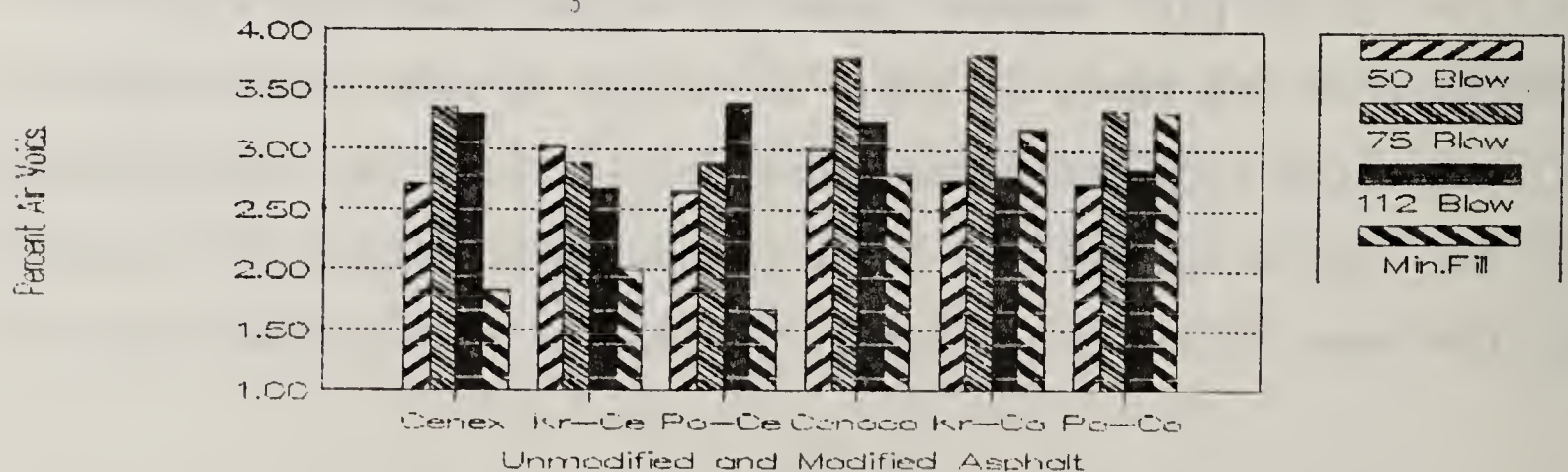


Figure M20. Air Voids for Conventional and Second Gradation Large Stone Aggregates Mix With and Without Mineral Filler, 75 & 112-Blow

the mineral filled specimen.

Percent air voids of the mineral filled specimens unmodified and modified Cenex at about 2 percent were lowest, as seen from Figure M20. But for modified Conoco, they were higher than those of specimens with 112 blows compaction.

The optimum asphalt contents for 6-inch specimens with 112 blows were lowest in the case of modified Cenex. For Conoco and modified Conoco optimum asphalt content of mineral filled 6-inch specimens were the lowest. Marshall stability of 112 blows compacted specimens were highest except for unmodified Cenex. For Cenex, mineral filled Cenex was highest. Flow for mineral filled specimens were highest. Unit weight of the 112 blows compacted specimens were highest in all cases except for Cenex; for Cenex mineral filled specimens was highest. Air voids of mineral filled 6-inch specimens with unmodified Cenex and Conoco, and modified Cenex were lowest while those of 112 blows compacted specimens were lowest for modified Conoco.

Comparison of Optimum Asphalt Content and Mix Properties at Optimum Asphalt Content Level of First and Second Aggregate Gradations with 75 and 112 Blows and Mineral Filler, 75 Blows

The relative differences of the optimum asphalt content and mix properties of 6-inch specimens with first and second gradations large stone aggregates (at optimum asphalt content) with 75 and 112 blows, and mineral filler with 75 blows compaction were analyzed and illustrated in a bar chart.

The optimum asphalt content of the 6-inch specimens with

first and second gradation large stone aggregates with unmodified and modified, Cenex and Conoco are presented in Figure M21. The asphalt content of the 75 blows compacted specimens with first gradation aggregates were between 4.5 and 5 percent, whereas those of second gradation aggregates were 4 and 4.5 percent for all modified and unmodified asphalt. The optimum asphalt content for specimens with first gradation aggregates were higher by 0.5 to about 1 percent. Also, for 112 blows compacted specimens the optimum asphalt content for second gradation aggregates were lower by about 0.5 to 1 percent, whereas for the specimens with mineral filler the differences were insignificant for unmodified and modified Cenex, and 0.5 for unmodified and modified Conoco. It was clear that mix design with second gradation aggregates would be more economical.

The stability of specimens with first and second gradation aggregates for modified and unmodified asphalt are presented in Figure M22. The stability values of the specimens with second gradation aggregates were higher than those of first gradation aggregates in all modified and unmodified, Cenex and Conoco. The stability values for the specimens with 75 blows were improved by 236 lbs. for Cenex, 684 lbs. for Kr-Ce, 134 lbs. for Po-Ce, 204 lbs. for Conoco, 137 lbs. for Kr-Co, and 562 lbs. for Po-Co. Similarly, the stability values for the specimens with second gradation with 112 blows compaction were higher than those for first gradation specimens with 112 blows by 193 lbs. for Cenex, 884 lbs. for Kr-Ce, 518 lbs. for Po-Ce, 233 lbs. for

## Optimum Asphalt Content—First And Second Gradation Large Stone Aggregates

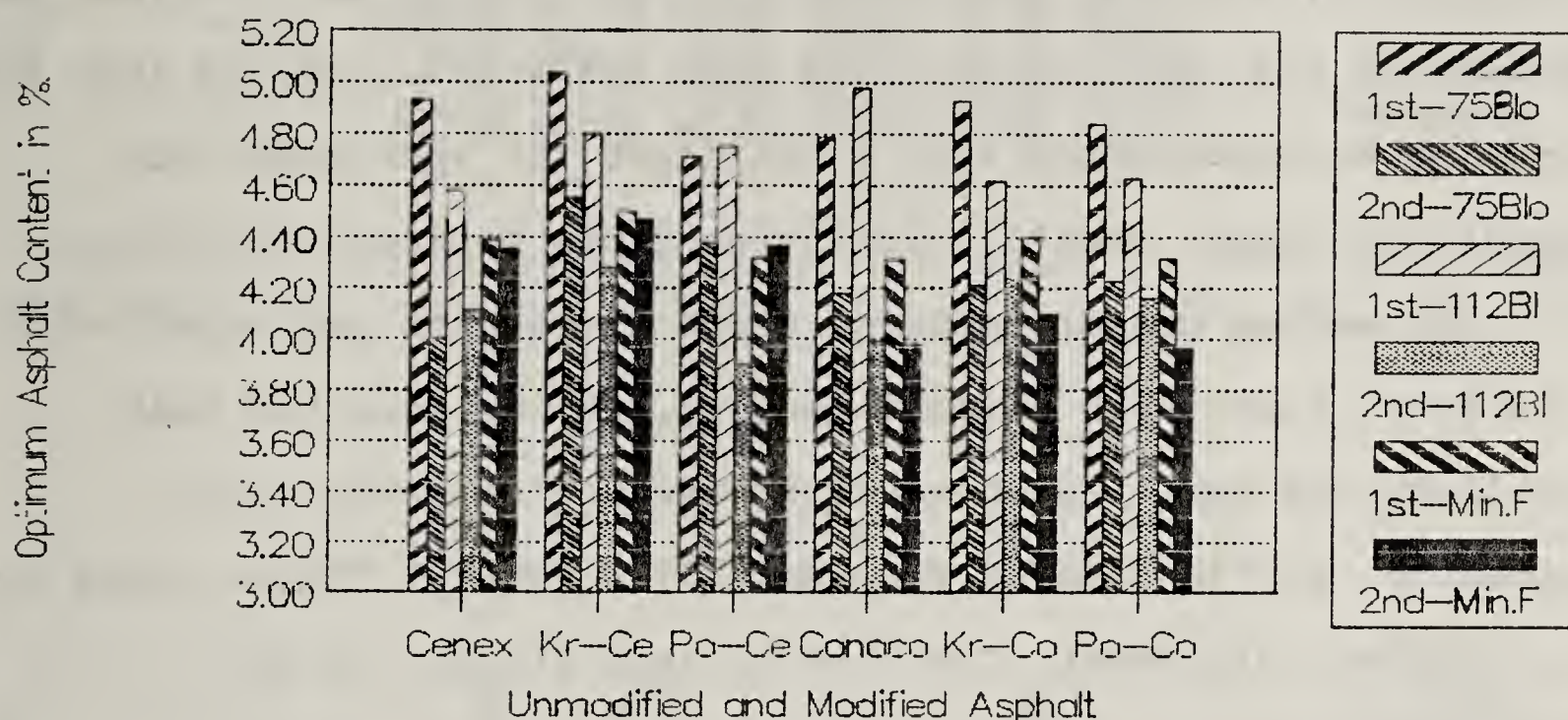


Figure M21. Optimum Asphalt Content for First and Second Gradation Aggregates Mix with and without Mineral Filler, at 75 and 112 Blows Compactions.

## Stability—First And Second Gradation Large Stone Aggregates

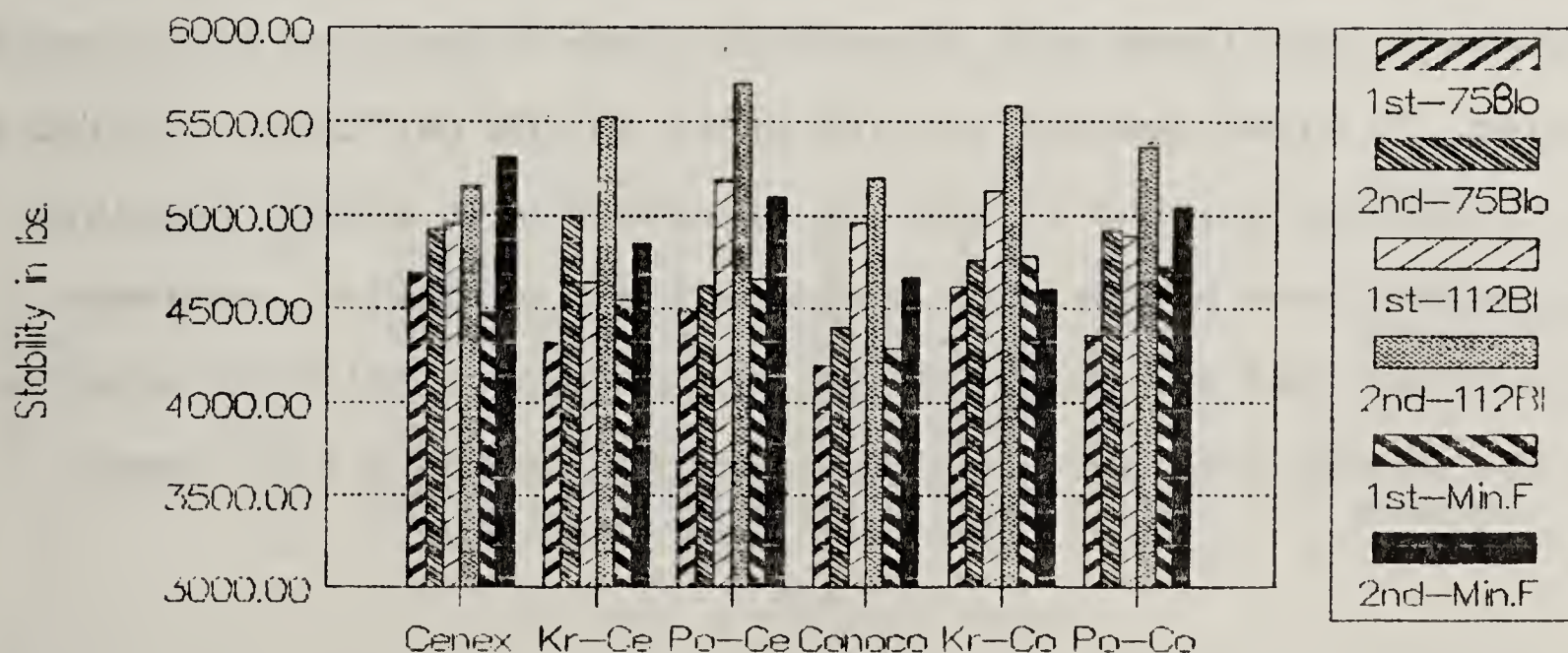


Figure M22. Stability for First and Second Gradation Aggregates Mix with and without Mineral Filler, at 75 and 112 Blows Compactions.

Conoco, 448 lbs. for Kr-Co, and 467 lbs. for Po-Co. The highest improvements were observed for Kr-Ce, Po-Ce, and Po-Co. Also, the stability values for second gradation specimens with mineral filler, 75 blows, were higher than those of the first gradation specimens by 832 lbs. for Cenex, 301 lbs. for Kr-Ce, 440 lbs. for Po-Ce, 374 lbs. for Conoco, -182 lbs. for Kr-Co, and 322 lbs. for Po-Co. The improvements were significant for specimens with unmodified Cenex. Negative improvement was noticed for Kr-Co.

The second gradation large stone aggregates was based on a 0.45 power curve with maximum density. It was expected that stability and unit weight would be greater than the first gradation. In the case of specimens with mineral filler, with Kr-Co, this was different. The lime mineral filler was an antistripping agent which could produce complex effects on aggregate-asphalt mix. This was observed for Kr-Co. Most of the samples with Kr-Co showed poor adhesion, when the samples were broken to conduct Rice specific gravity tests in both first and second gradation specimens. This kind of stripping was also observed in Kr-Ce with mineral filler, but to a lesser extent.

The unit weight of first and second gradation large stone aggregates specimens with 75 and 112 blows compaction and mineral filler, 75 blows compaction, are shown in the bar chart of Figure M23. The unit weights of all the specimens with second gradation aggregates were higher than those of first gradation specimens with unmodified and modified, Cenex and Conoco. This was expected as the second gradation aggregates were based on a 0.45 power

### Unit Weight—First and Second Gradations Large Stone Aggregates

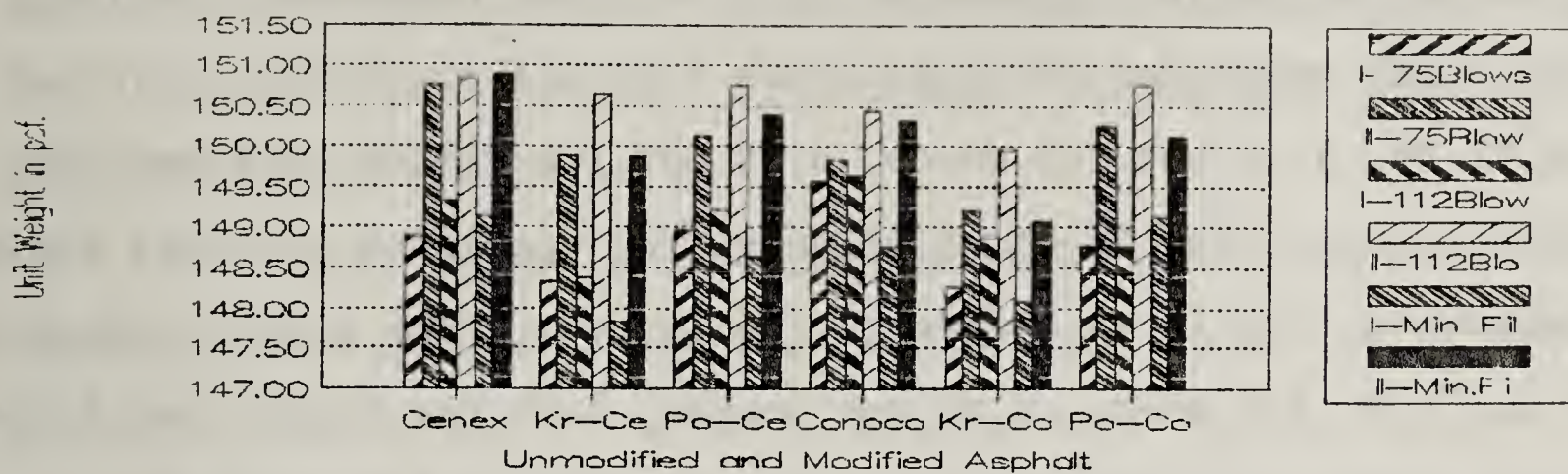


Figure M23. Unit Weight for First and Second Gradation Aggregates Mix with and without Mineral Filler, at 75 and 112 Blows

### Marshall Flow—First and Second Gradations Large Stone Aggregates

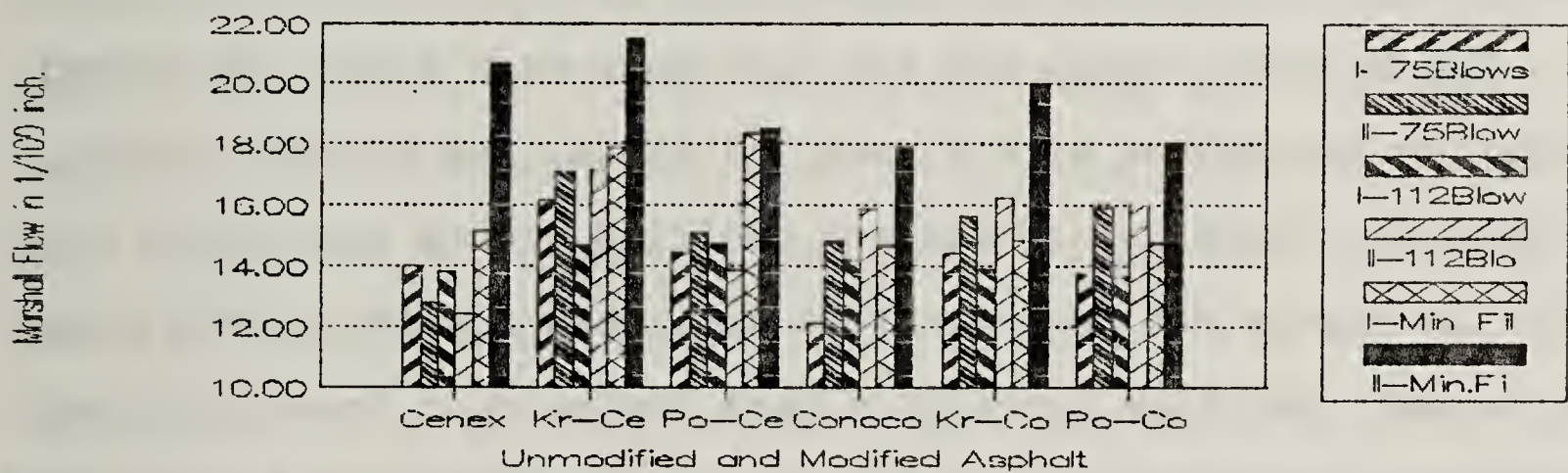


Figure M24. Flow for First and Second Gradation Aggregates Mix with and without Mineral Filler, at 75 and 112 Blows Compactions.

### Air Voids—First and Second Gradations Large Stone Aggregates

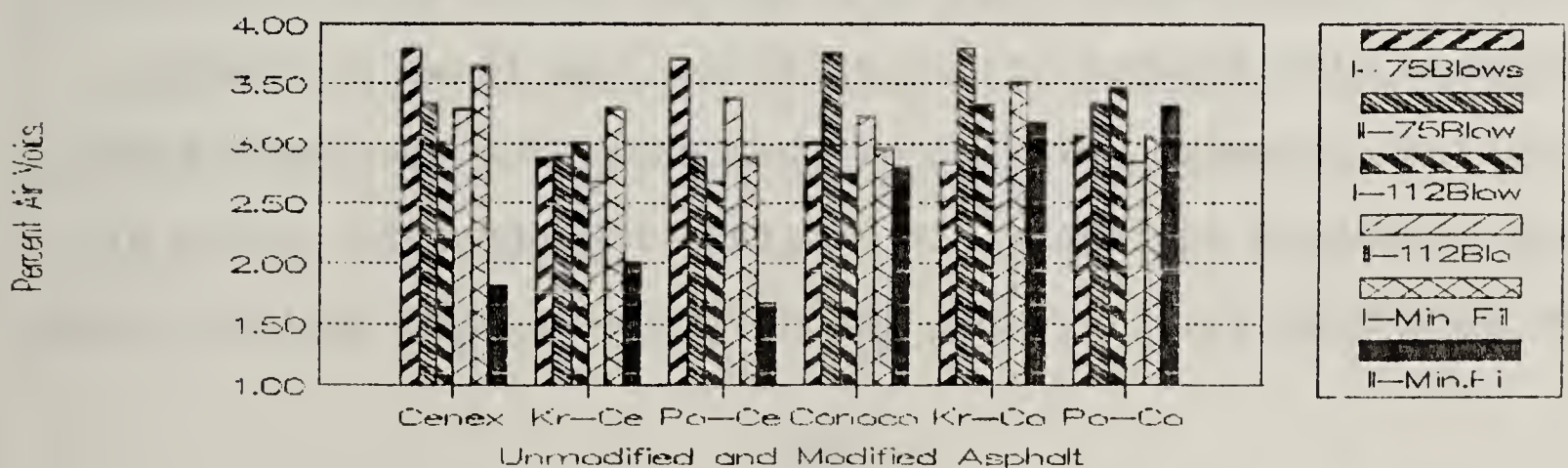


Figure M25. Air Voids for First and Second Gradation Aggregates Mix with and without Mineral Filler, at 75 and 112 Blows

curves with maximum unit weight. The improvements of unit weight of second gradation aggregates with 75 blows compacted specimens over first gradation specimens were 1.87 pcf for Cenex, 1.56 pcf for Kr-Ce, 1.18 pcf for Po-Ce, 0.25 pcf for Conoco, 0.94 pcf for Kr-Co, and 1.5 for Po-Co. Similarly, for specimens with 112 blows compaction, the improvements in lbs. were 1.5 for Cenex, 2.24 for Kr-Ce, 1.56 for Po-Ce, 0.81 for Conoco, 1.06 for Kr-Co, and 2 for Po-Co. Again, for the specimens with mineral filler with 75 blows, the differences were 1.74 for Cenex, 2.05 for Kr-Ce, 1.74 for Po-Ce, 1.56 for Conoco, 0.99 for Kr-Co, and 0.99 for Po-Co. The improvements for unmodified and modified Cenex were higher than those for unmodified and modified Conoco.

The Marshall flows for the specimens with first and second gradation aggregates with 75 and 112 blows, and mineral filler, 75 blows for both unmodified and modified, Cenex and Conoco are shown in Figure M24. For 75 blows compacted specimens, the flows for second gradation aggregates were higher than those of first gradation aggregates except for Cenex. The differences were about 1/100 to 2/100 inch. For the specimens with 112 blows compaction, the second gradation aggregates for modified Conoco, Kr-Co and Po-Co, and Kr-Ce were higher than those of first gradation aggregates by about 1.5/100 to 2.33/100 inch. But for the specimens with mineral filler 75 blows, the flows of second gradation aggregate were higher than those for specimens with first gradation aggregate. In general, the absolute values of flow were high in all cases. The differences were 5.54 for Cenex,

3.59 for Kr-Ce, 0.14 for Po-Ce, 3.24 for Conoco, 5.14 for Kr-Co, and 3.25 for Po-Co. The difference for Po-Ce was the lowest. The flow value for the specimens with mineral filler were high for 4-inch and 6-inch specimens.

As the unit weight of specimens with second gradations aggregate were higher than those of specimens with first gradation aggregates, it would be assumed that the air voids would be less, but they were not. The reason for the higher unit weights was due to the maximum unit weight gradation of the second gradation aggregate based on a 0.45 power curve. The values of the air voids for both specimens with first and second gradations aggregates with unmodified and modified, Cenex and Conoco, are presented in Figure M25. Air voids for 75 blows compacted specimens with first and second gradations aggregates were 3.79 and 3.34 for Cenex, 2.86 and 2.88 for Kr-Ce, 3.76 and 2.88 for Po-Ce, 3 and 3.75 for Conoco, 2.83 and 3.78 for Kr-Co, and 3.06 and 3.33 for Po-Co respectively. Percent air voids for specimens with 112 blows compaction for first and second gradation aggregates were 3 and 3.28 for Cenex, 3 and 2.67 for Kr-Ce, 2.67 and 3.38 for Po-Ce, 2.74 and 3.22 for Conoco, 3.32 and 2.78 for Kr-Co, and 3.46 and 2.86 for Po-Co respectively. Similarly, percent air voids for specimens with mineral filler, 75 blows for first and second gradations aggregates were 3.63 and 1.81 for Cenex, 3.29 and 2 for Kr-Ce, 2.88 and 1.67 for Po-Co, 2.95 and 2.79 for Conoco, 3.5 and 3.17 for Kr-Co, and 3.06 and 3.31 for Po-Co. The air voids for second gradation aggregates

with modified and unmodified Cenex were low.

### Observations

In some cases, the Cenex and Conoco asphalt modified with Kraton stripped from the aggregate. This was noticed when the samples were broken to conduct Rice specific gravity tests. For the samples with stripped aggregate, the stability values were found to be low. This may have been caused by non-uniformly mixed modified asphalt or by some static electric charge on the aggregate surface.

The standard deviations of the stability and density results were found to be large compared to those of the 4-inch specimens. This may be because of the large rounded gravel in the large stone mixes. The absolute values of these parameters are also higher compared to those of 4-inch molded specimens. Care must be taken to see that well rounded gravel is excluded from the aggregate. The large stone stock pile contains considerable amounts of the rounded stone. The city of Denver specification requires fractured faces of at least 2 or more.

The 75 blows with the 22.5 lbs. hammer caused breakage of some large stones. The breakage occurred mostly as side chips off of the large stones. The breakage of large stones in the middle was not extensive. The breakage may have been caused by improper alignment and segregation of large stone in the mix. Most breakages were noticed in the stripped Kraton modified asphalt mix.

Segregation of large stone and smaller aggregate were

observed in the mixes. The bulk specific gravity on segregated samples did not produce consistent results. Care must be taken not to drop the large stone size aggregate into the mold as it tends to fall first. A uniformly mixed sample should be poured into the mold. The segregation of large stone can be noticed by the unusual honey comb in the molded specimen, following compaction.

The absolute values of the Marshall stability, flow and density are high in 6-inch molded specimen tests compared to those of 4-inch molded specimens.

The Marshall tests were repeated on those specimens for which results were suspiciously irregular. The repeated results confirmed with the representative results. Irregularities were likely caused by random errors in the long process of producing and testing of the specimens. Moreover, different personnel were involved in the whole process.

### Conclusion

The Marshall method of mix design can be successfully applied to large stone aggregate mixes with some modifications: the use of the 6-inch mold instead of the 4-inch mold; the compactive effort from the 22 1/2 lbs. hammer requires an adjustment in the number of blows 75 and 112 blows.

The procedures for the 6-inch molded specimens are almost the same as for the 4-inch molded specimens, with little variation, but considerable more care. The 6-inch molded specimen for large stone is applicable to both unmodified and modified

asphalt. Optimum asphalt content for modified asphalt can be obtained in the same way as unmodified asphalt for 6-inch molded specimens.

The absolute value of the Marshall stability, flow and density are higher for the 6-inch mold. The effect of modification is more pronounced in the case of 6-inch molded tests compared to the 4-inch molded specimen tests. The parameter values are more magnified. Therefore, the effect of variables such as aggregate size, composition and compaction, effects of different brands of asphalt and modified asphalt are easily observed.

The aggregate gradations are an important factor in the mix design. The gradation close to the maximum density line is superior to other gradations. The fractured faces in a large stone aggregate is also an important factor in the mix design. The large stone aggregate with more fractured faces is superior to smooth rounded aggregates. This was demonstrated by the use of at least two fractured faces in the above tests.

Compaction effort is another factor to be considered. The stability values for the specimen with aggregate gradation close to maximum density on a 0.45 power curve with 112 blows compaction produced consistent effect of the modifier in the asphalt. For both Kraton and Polybilt modified Cenex, the Marshall stability values are large compared to those of the unmodified Cenex, indicating an improvement in the mix design parameters. In the case of both the Kraton and the Polybilt

modified Conoco asphalt, Marshall mix design parameter values are higher compared to those of the unmodified Conoco. This shows that both the Kraton and the Polybilt modified Conoco would perform better than the unmodified Conoco. However, the improvement may be within the range of testing variability for the Marshall test procedure.

The effect of shape, texture, and quantity of the large stone aggregate in a mix is so profound that the effect of modified asphalt may be distorted.

Mineral filler is better for unmodified Cenex and Conoco in a large stone mix. It improved the mix properties while reducing the optimum asphalt content value. However, mineral filler is not good for Kraton modified Cenex or Conoco. Mineral filler caused more stripping in Kraton modified Conoco and Cenex, and produced inconsistent results.

Higher compaction of 112 blows resulted in reduction of asphalt content. The optimum asphalt content for second gradation aggregate was the lowest with 112 blows compaction. A higher percentage of large stone in a mix resulted in a reduction in asphalt requirements. The use of large stone is economical.

### Recommendations

The following areas of study will be introduced during the final stages of Phase II. Hopefully, approval of Phase III will allow completion of these investigations.

1. Evaluate the effect of " rounded" large stone aggregate

on the Marshall test parameter values against a completely broken faced aggregate. Study the effect of flat crushed stone forming a laminated layer of aggregate bonded asphalt matrix. Run tests on uniformly graded, stone filled, and open graded aggregate mixes.

2. Statistical analysis to observe the effects of variables such as modified asphalt, round and broken aggregate etc.

3. Run the 6-inch molded specimen on the normal size aggregate, less than 1 inch nominal size. Determine if the higher values of stability , flow and density for 6-inch specimens are caused by the larger sample size (4050 grams) or were actually a result of the large stone portion in the aggregate mix.

4. Run tests with different aggregate gradation based on the .45 power curve and other theoretical basis.

5. Kneading compaction may not cause the breakage of aggregate, and may simulate actual field compaction. A comparison of Marshall parameters produced by the California kneading compactor to those of the Marshall hammer would be beneficial.

6. Evaluate the freeze and thaw effect on the large stone mix design by conducting Lottman tests on 6-inch specimens.

7. Correlate Marshall Method results, namely stability, with SHRP performance based testing being done by UC-Berkeley.

8. Evaluate the Marshall stability number as a rutting indicator, through the correlations with UC-Berkeley.

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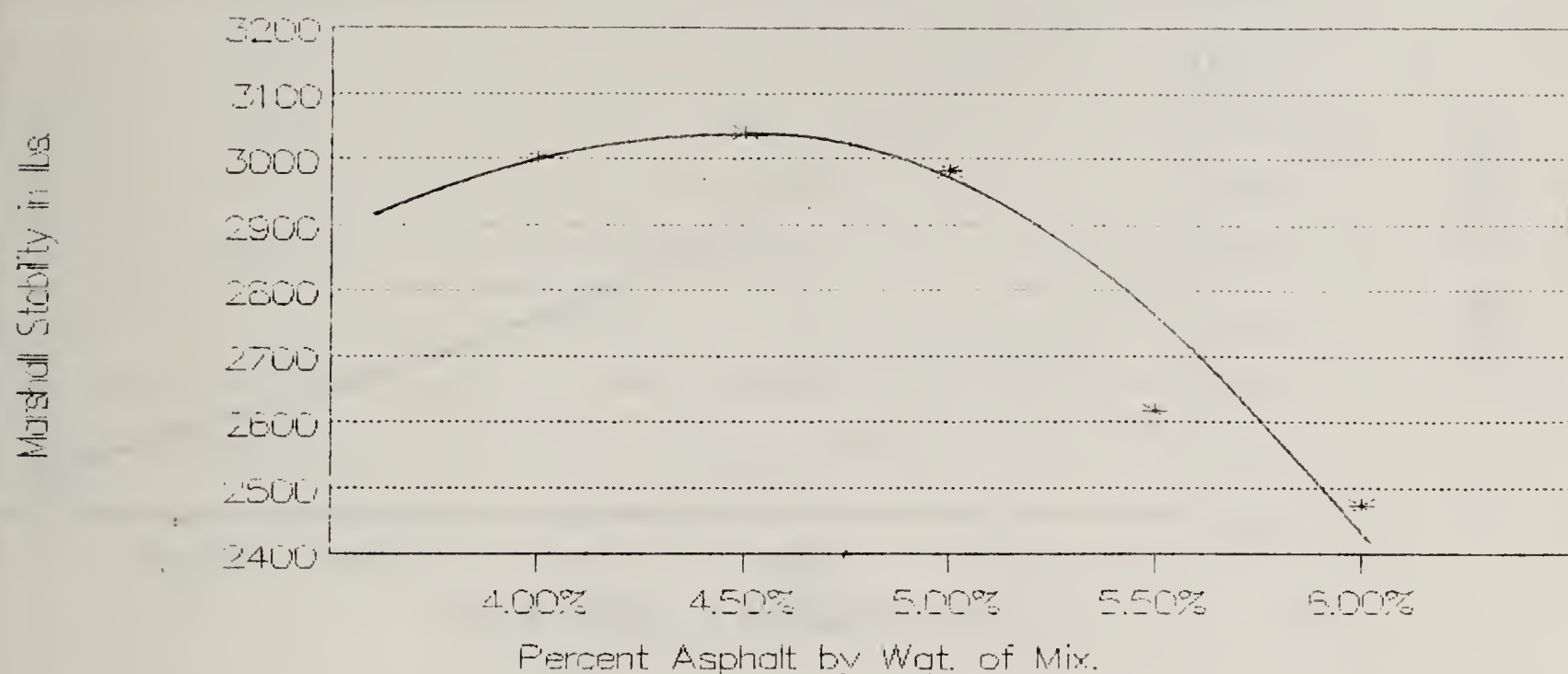
Appendix A

Marshall Test Properties Curves for 4-inch Specimens  
with  
Mineral Filler 50 Blows



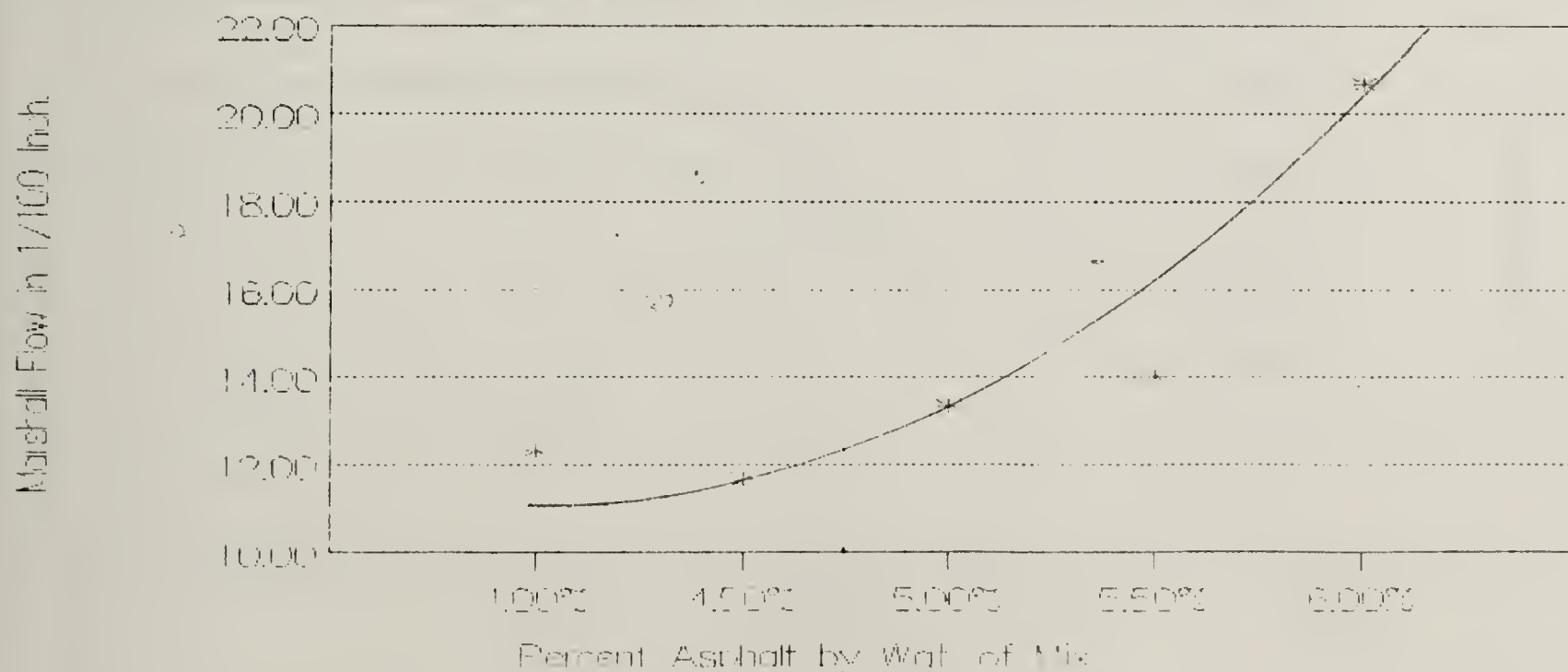
# Unmodified Cenex - 4 in. Mold Specimen

## Mineral Filler - Marshall Stability.



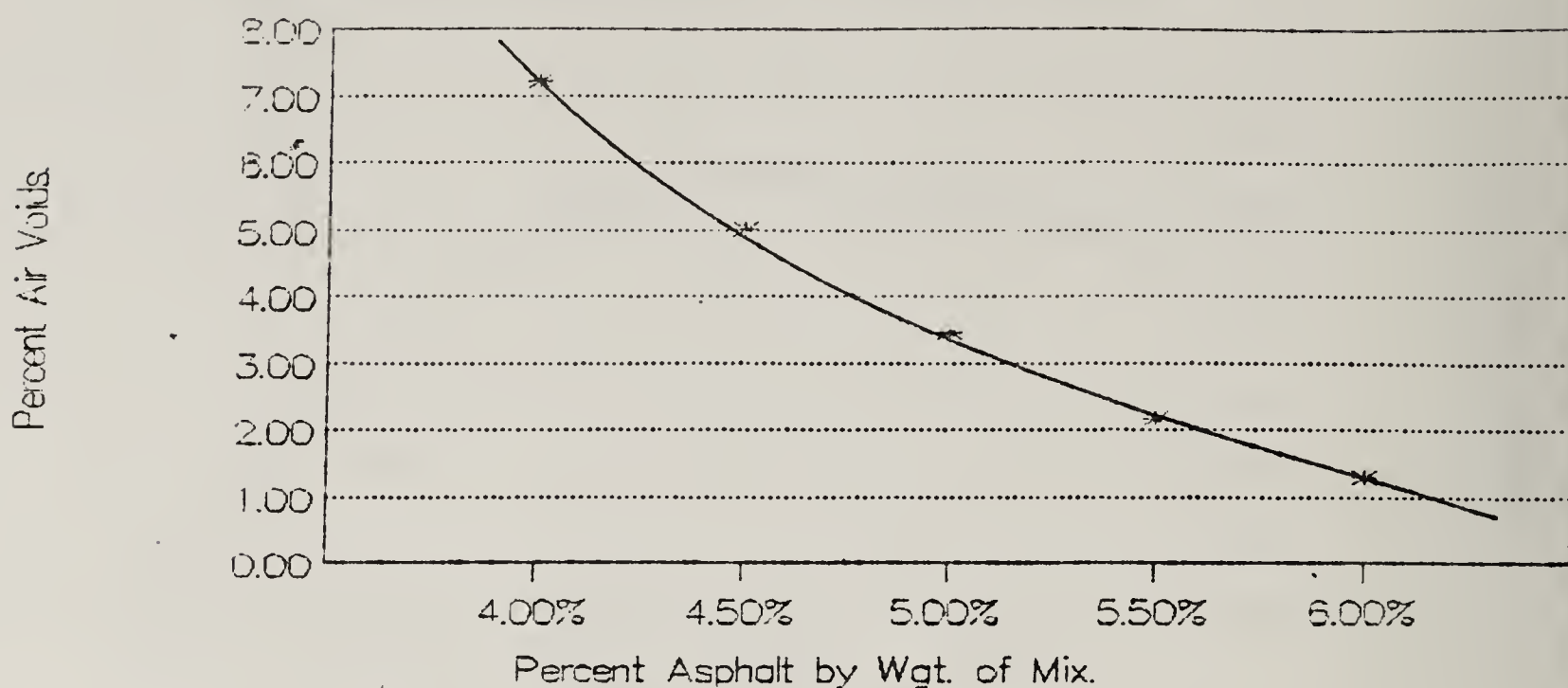
# Unmodified Cenex - 4 in. Mold Specimen

## Mineral Filler - Marshall Flow.



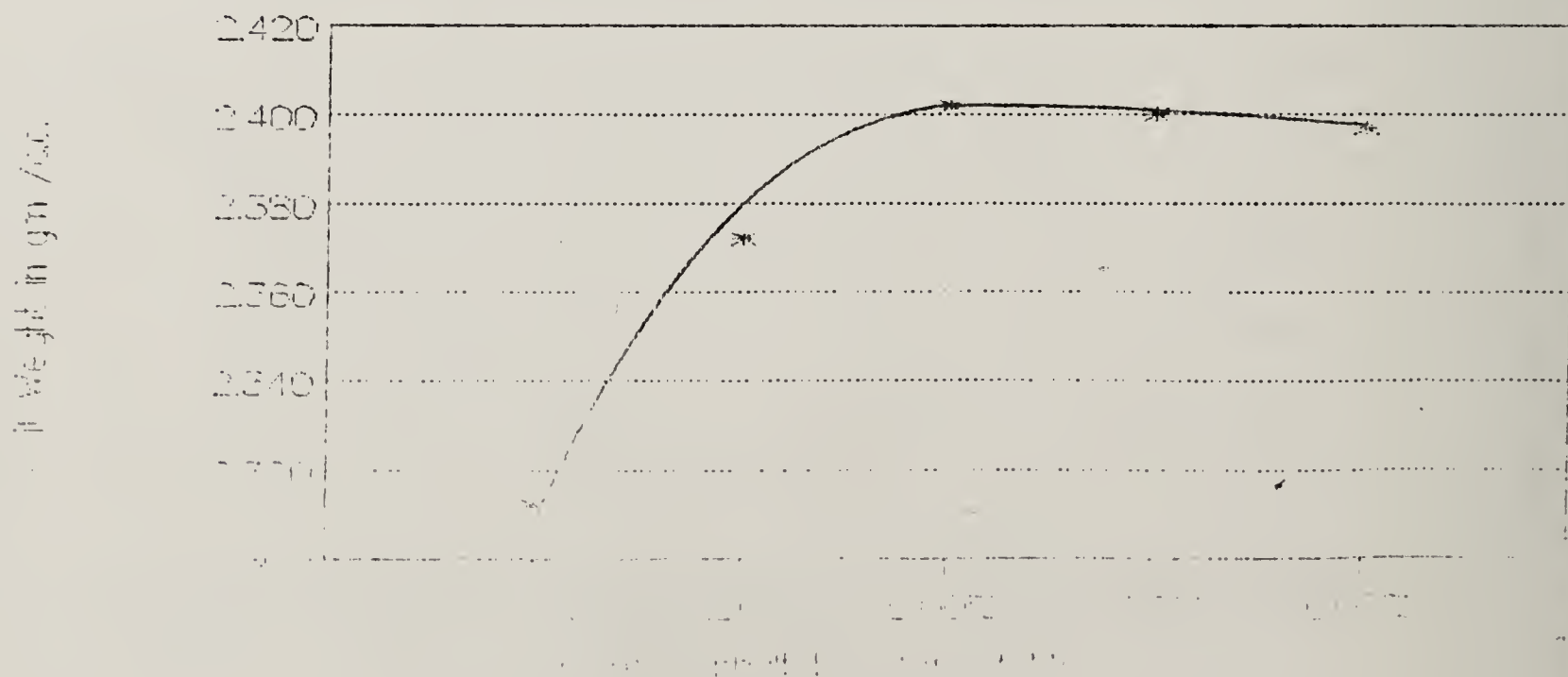
# Unmodified Cenex-4 in. Mold Specimen

Mineral Filler – Percent Air Voids.

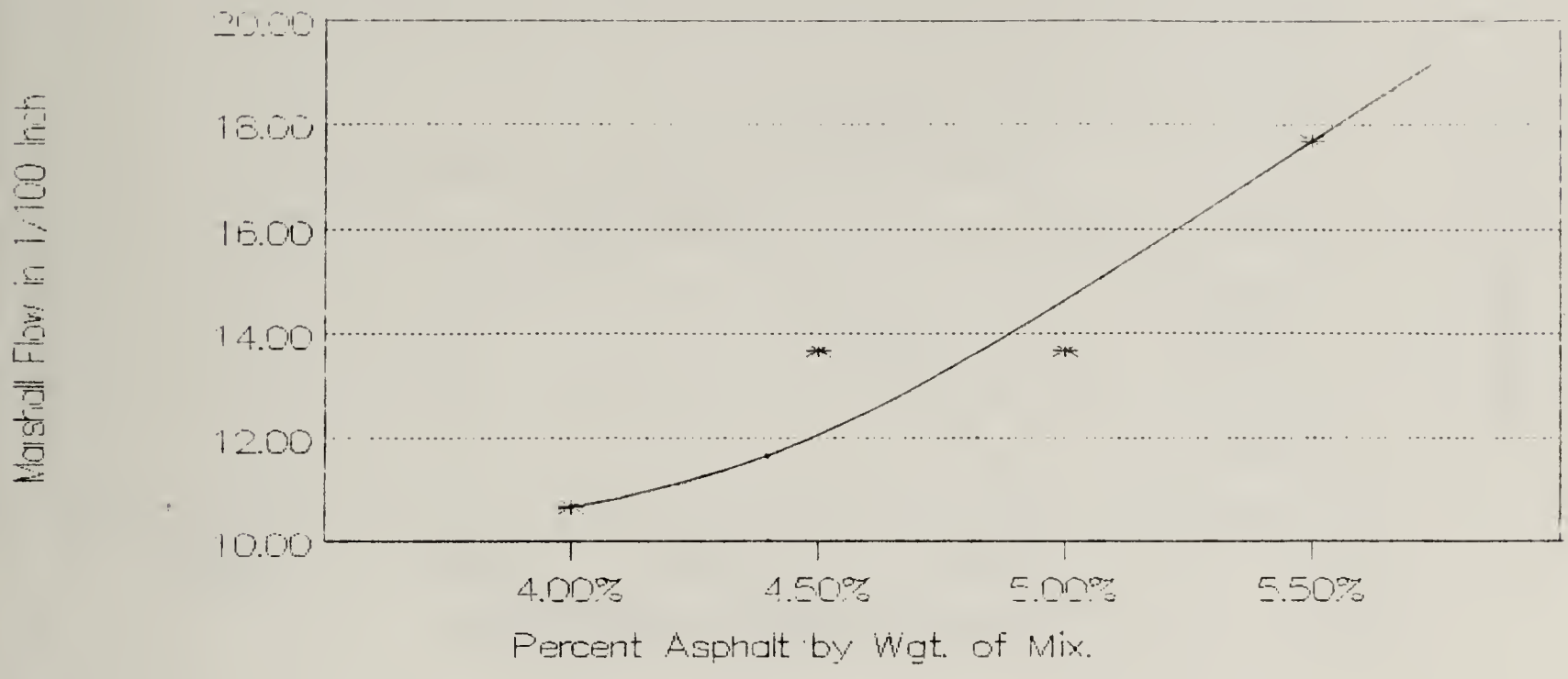


# Unmodified Cenex-4 in. Mold Specimen

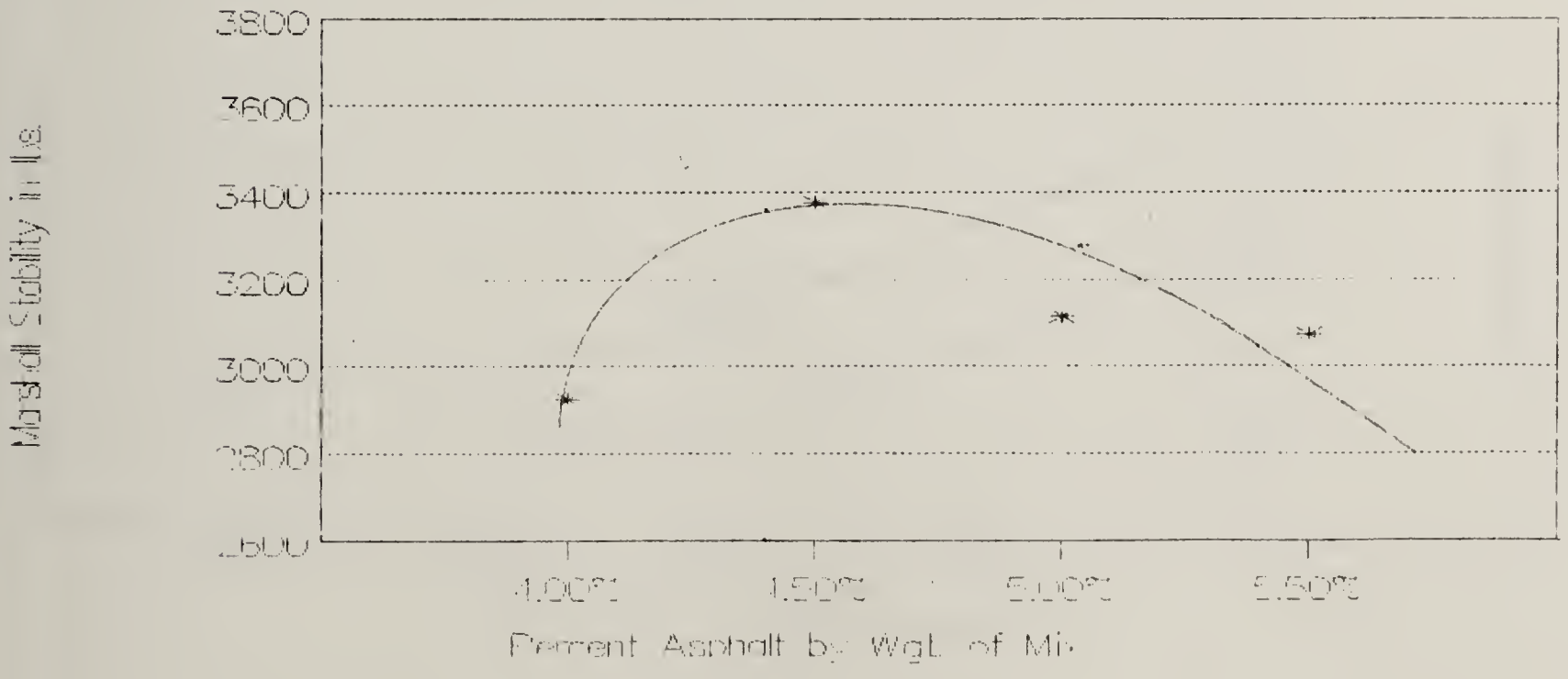
Mineral Filler – Unit Weight in gm/c.c.



Kraton Mod. Cenex - 4 in. Mold Specimen  
Mineral Filler - Marshall Flow.

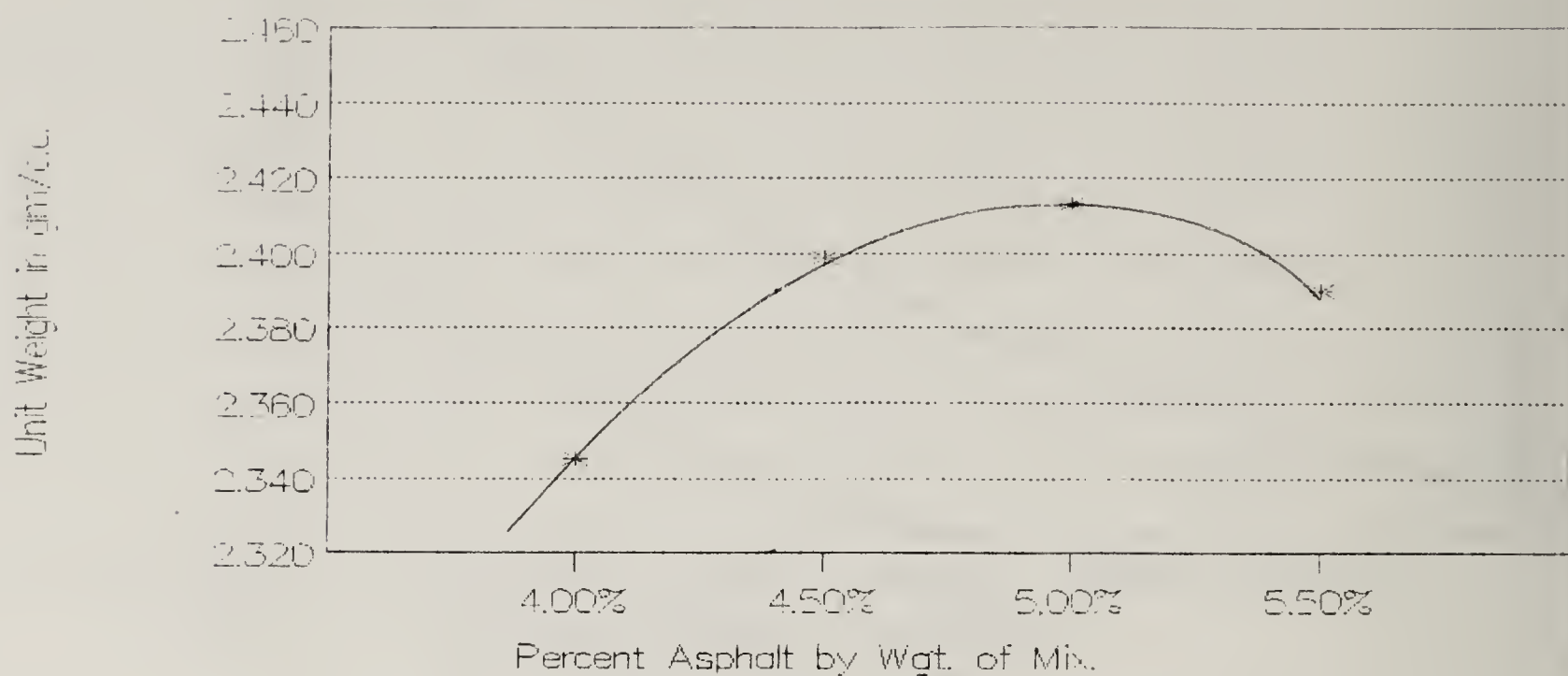


Kraton Mod. Cenex - 4 in. Mold Specimen  
Mineral Filler - Marshall Stability



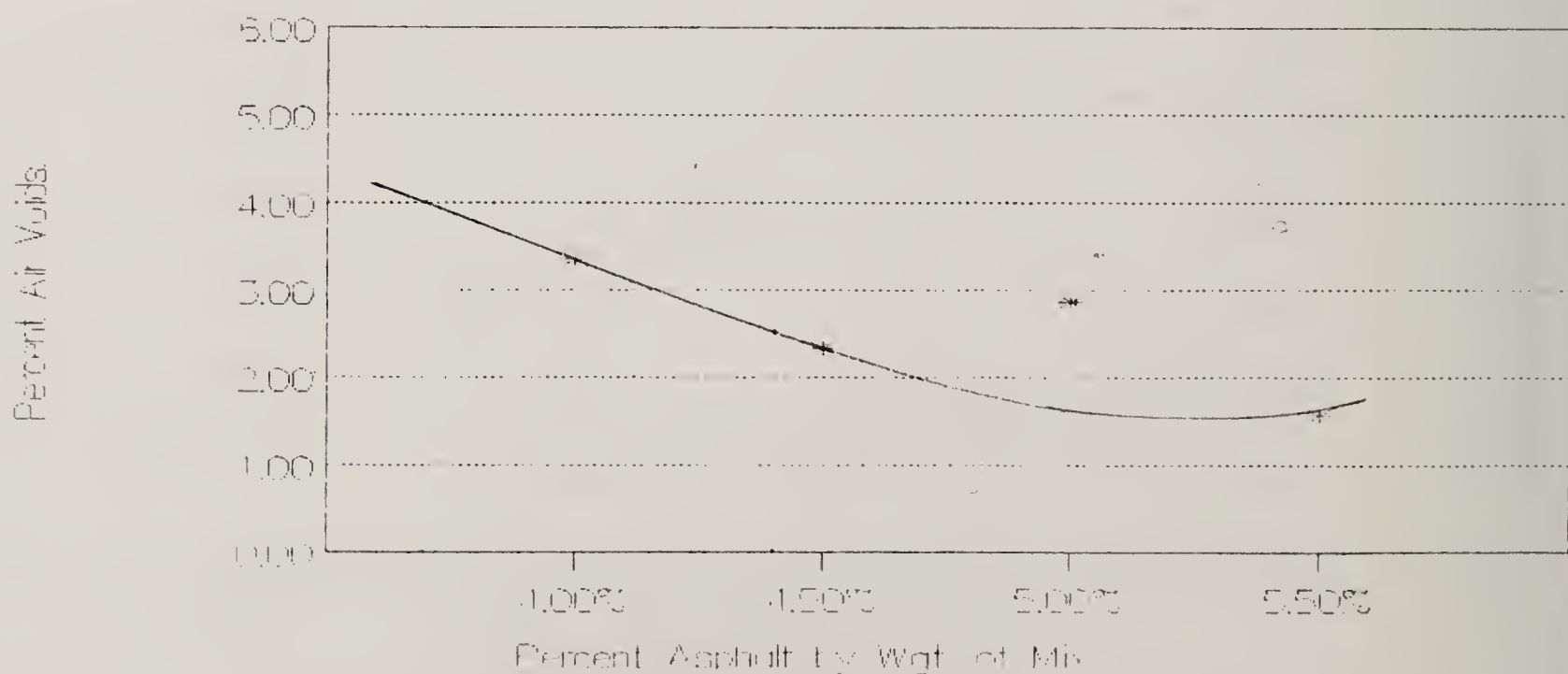
# Kraton Mod. Cenex - 4 in. Mold Specimen

Mineral Filler - Unit Weight in gm/c.c.

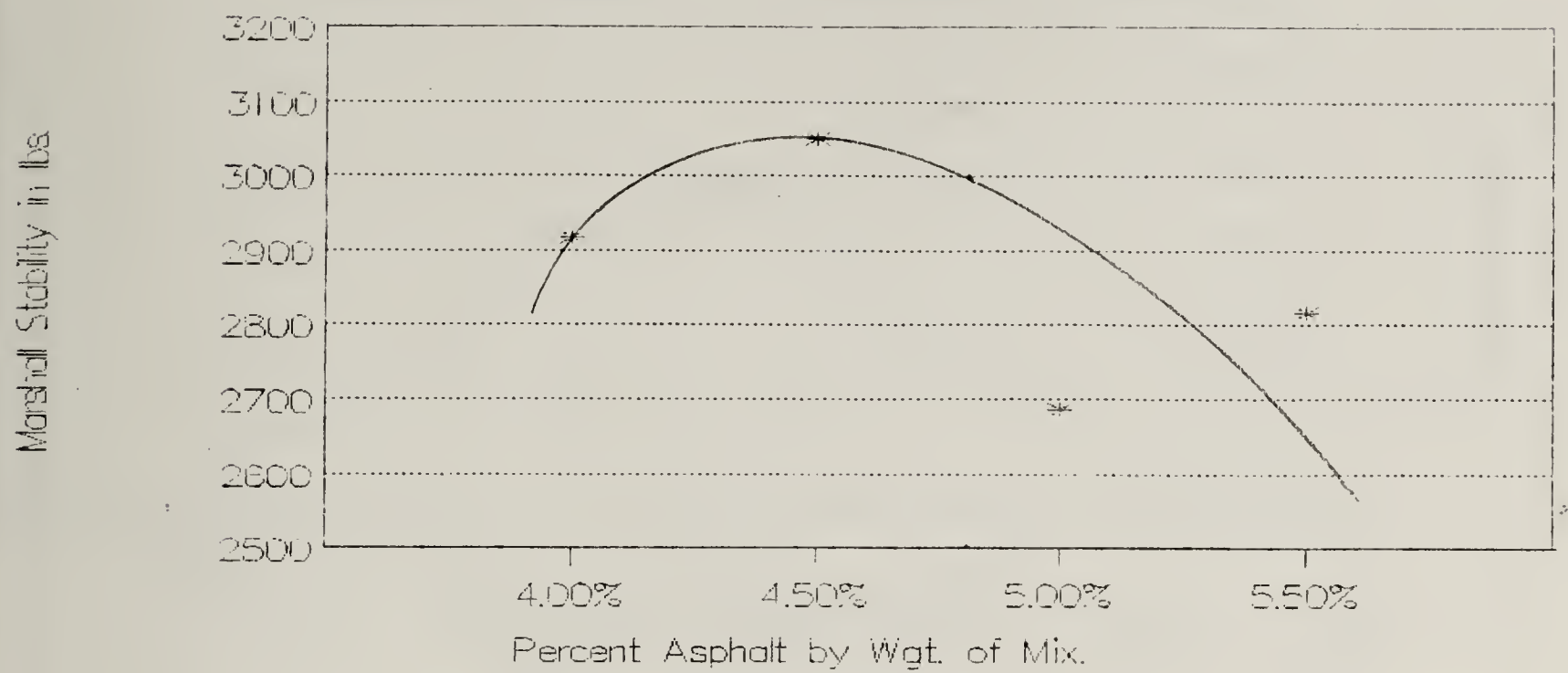


# Kraton Mod. Cenex - 4 in. Mold Specimen

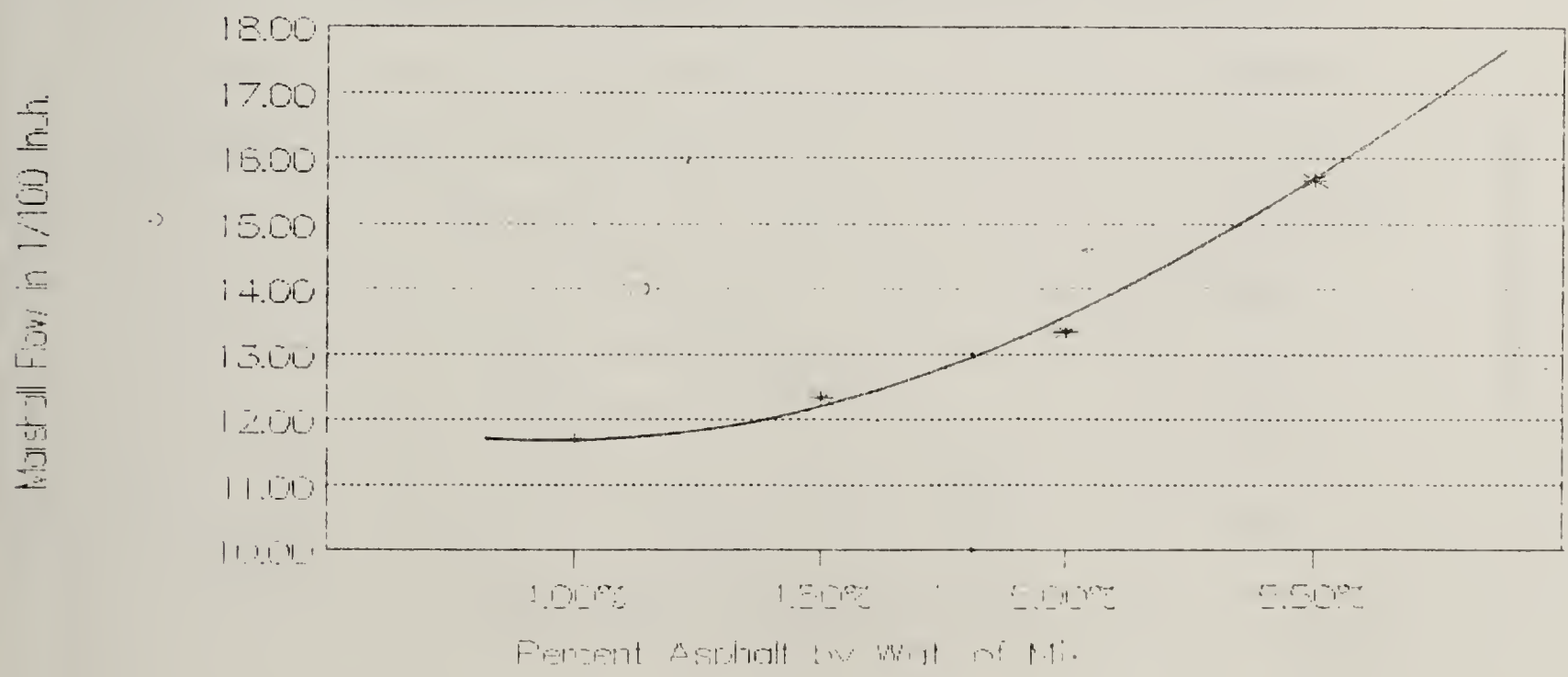
Mineral Filler - Percent Air Voids.



Polybilt Mod. Cenex-4 in. Mold Specimen  
Mineral Filler - Marshall Stability.

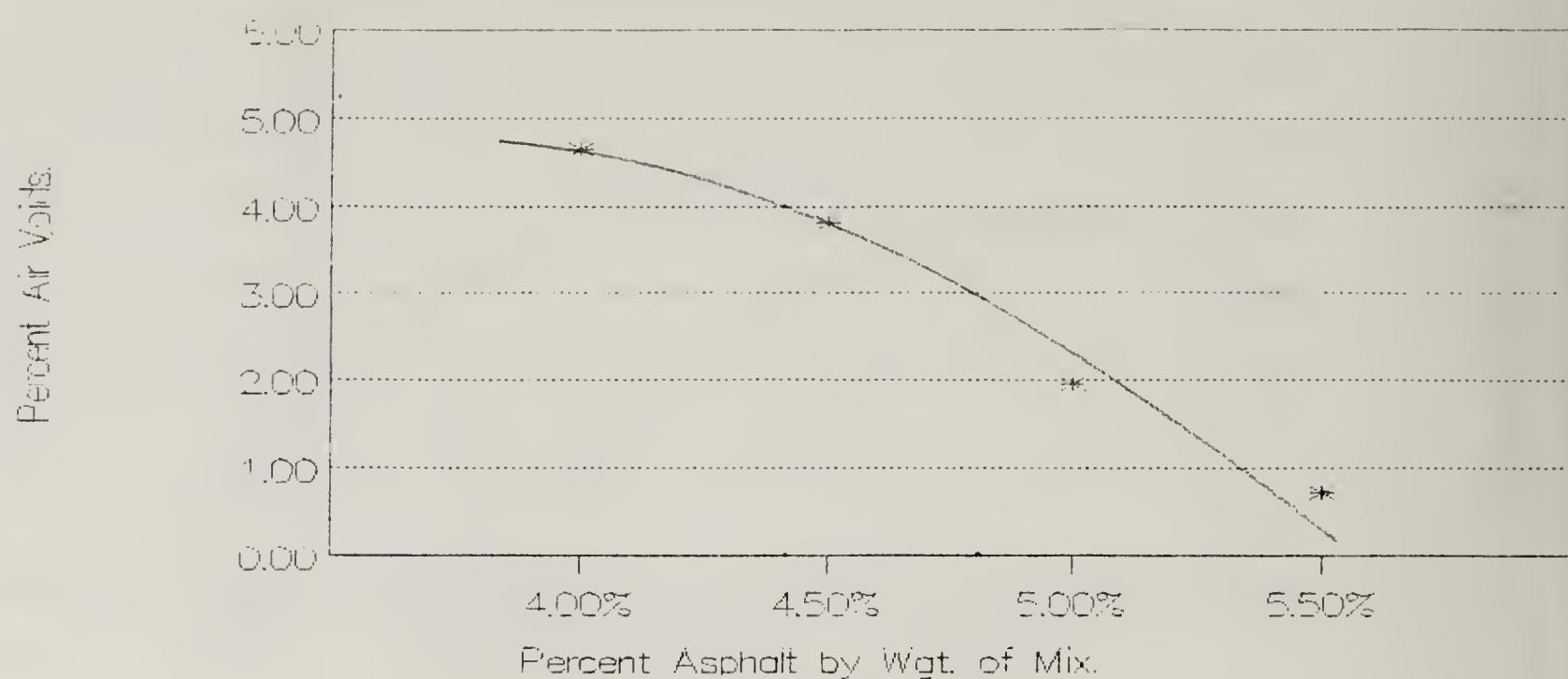


Polybilt Mod. Cenex-4 in. Mold Specimen  
Mineral Filler - Marshall Flow.



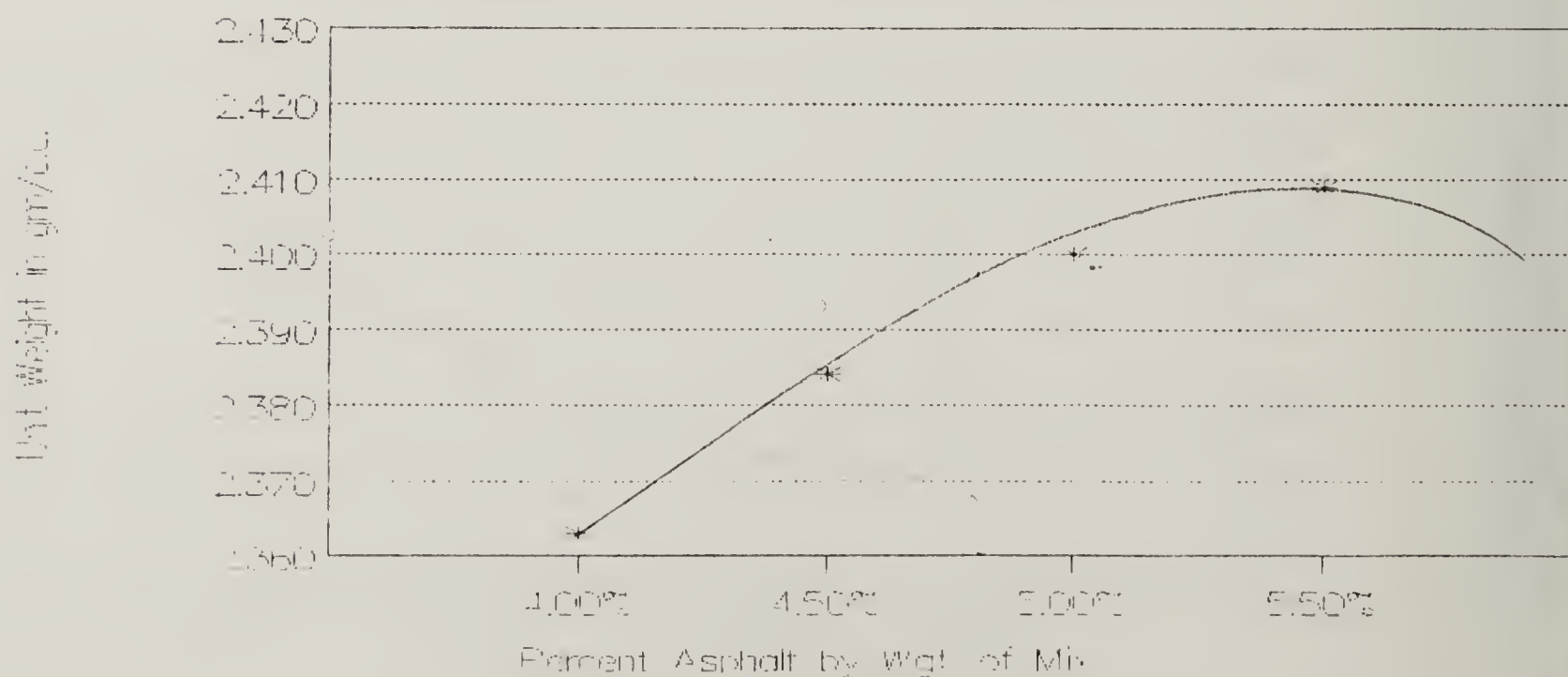
# Polybilt Mod. Cenex-4 in. Mold Specimen

## Mineral Filler - Percent Air Voids.



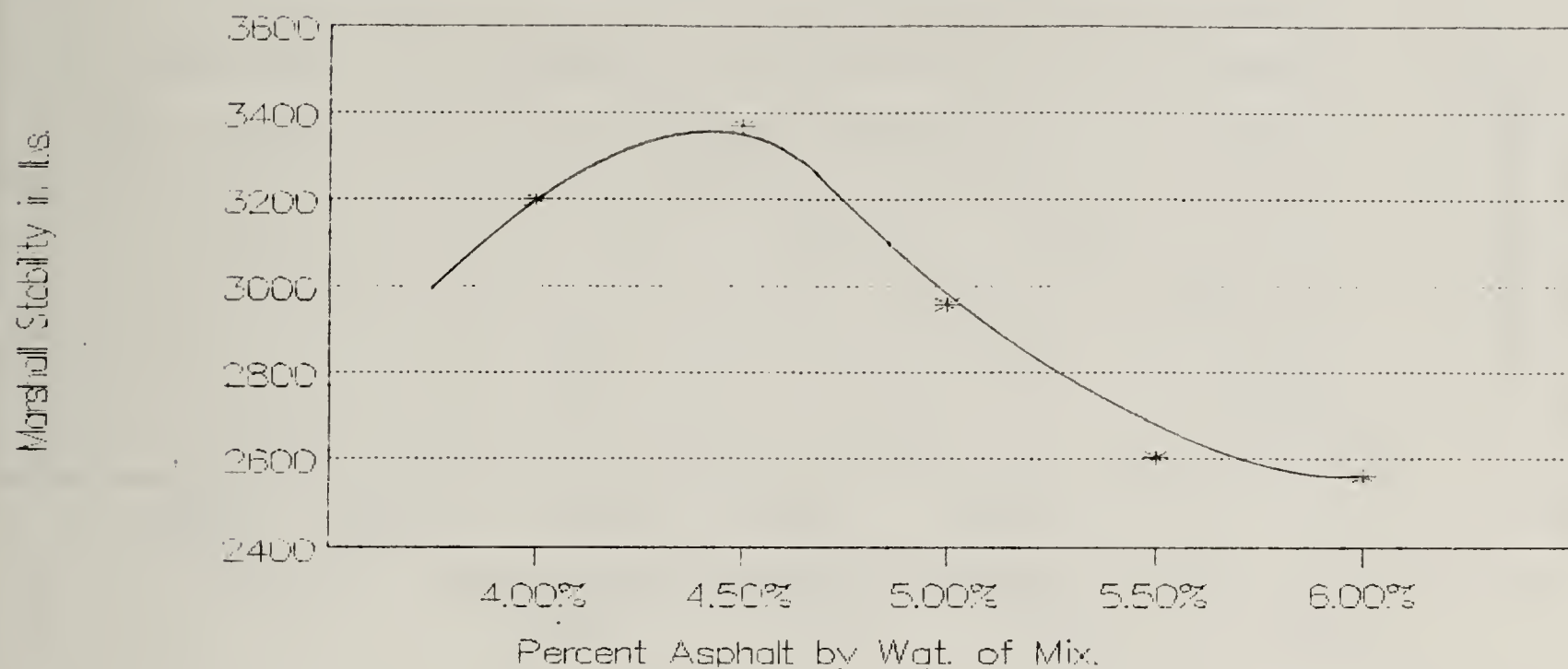
# Polybilt Mod. Cenex-4 in. Mold Specimen

## Mineral Filler - Unit Weight in gm/c.c.



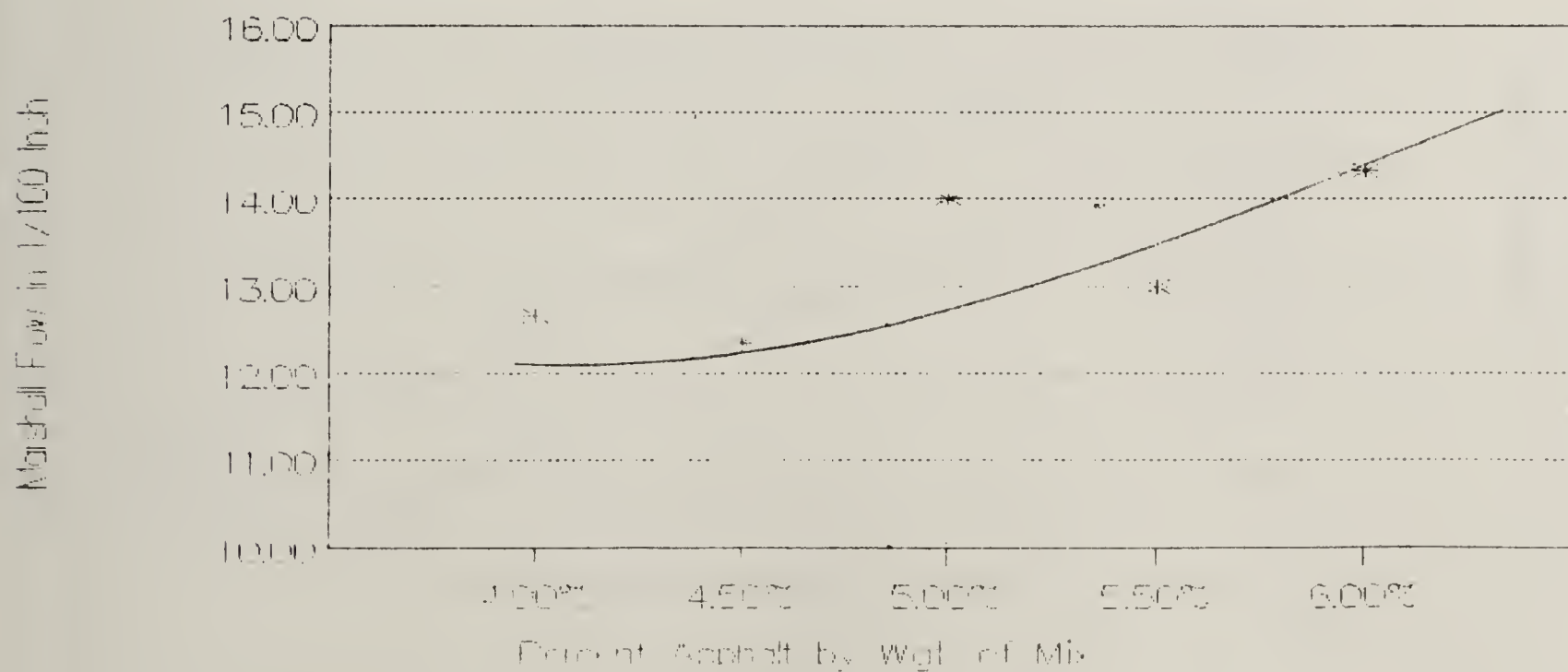
# Unmodified Conoco - 4 in. Mold Specimen

## Mineral Filler - Marshall Stability.



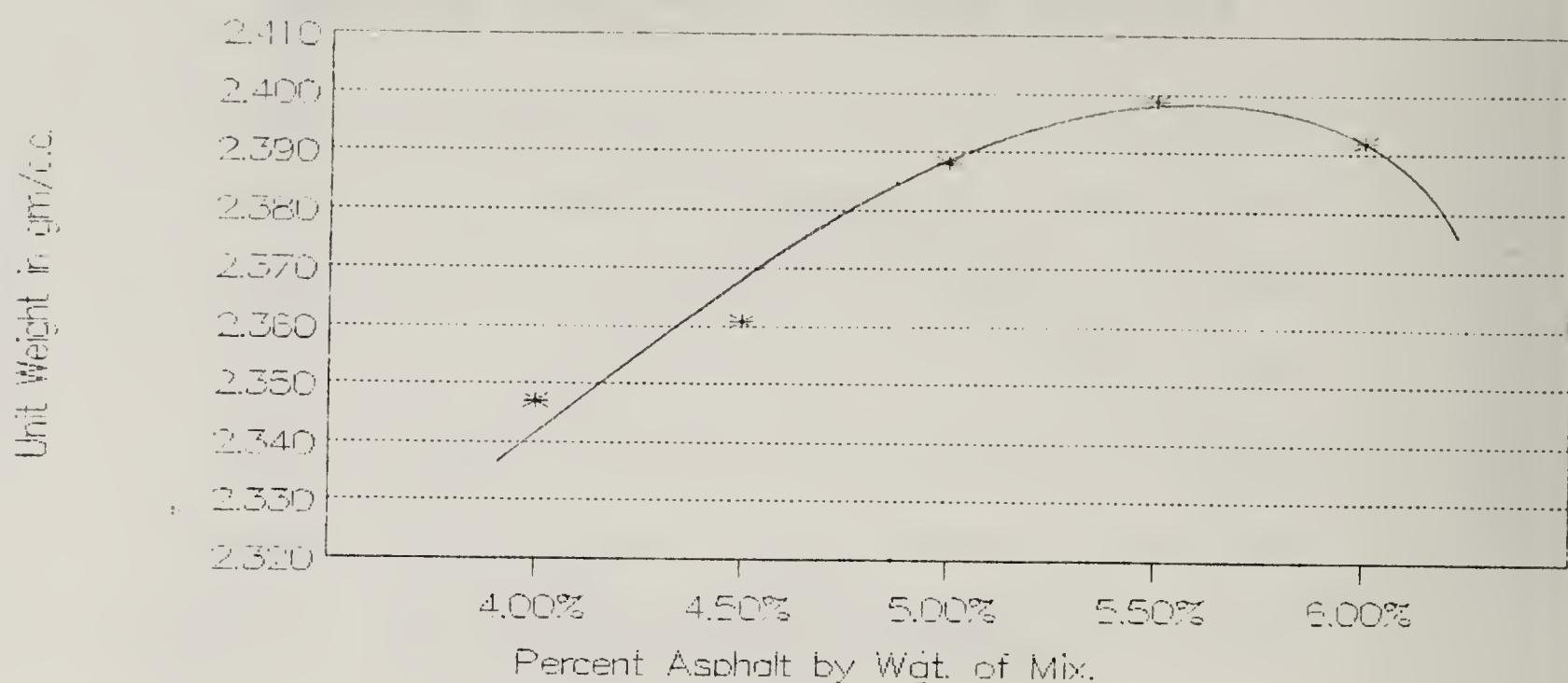
# Unmodified Conoco - 4 in. Mold Specimen

## Mineral Filler - Marshall Flow.



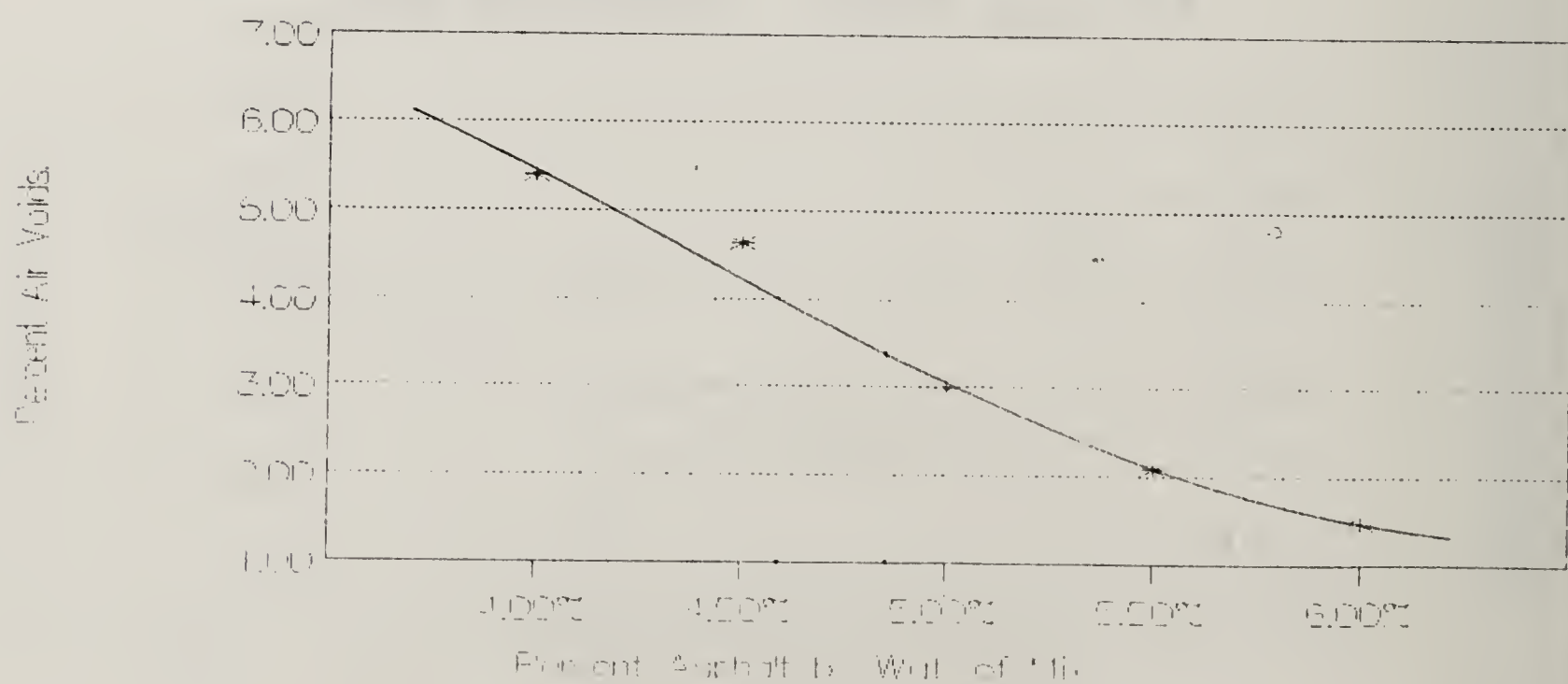
# Unmodified Conoco - 4 in. Mold Specimen

Mineral Filler - Unit Weight in gm/c.c.



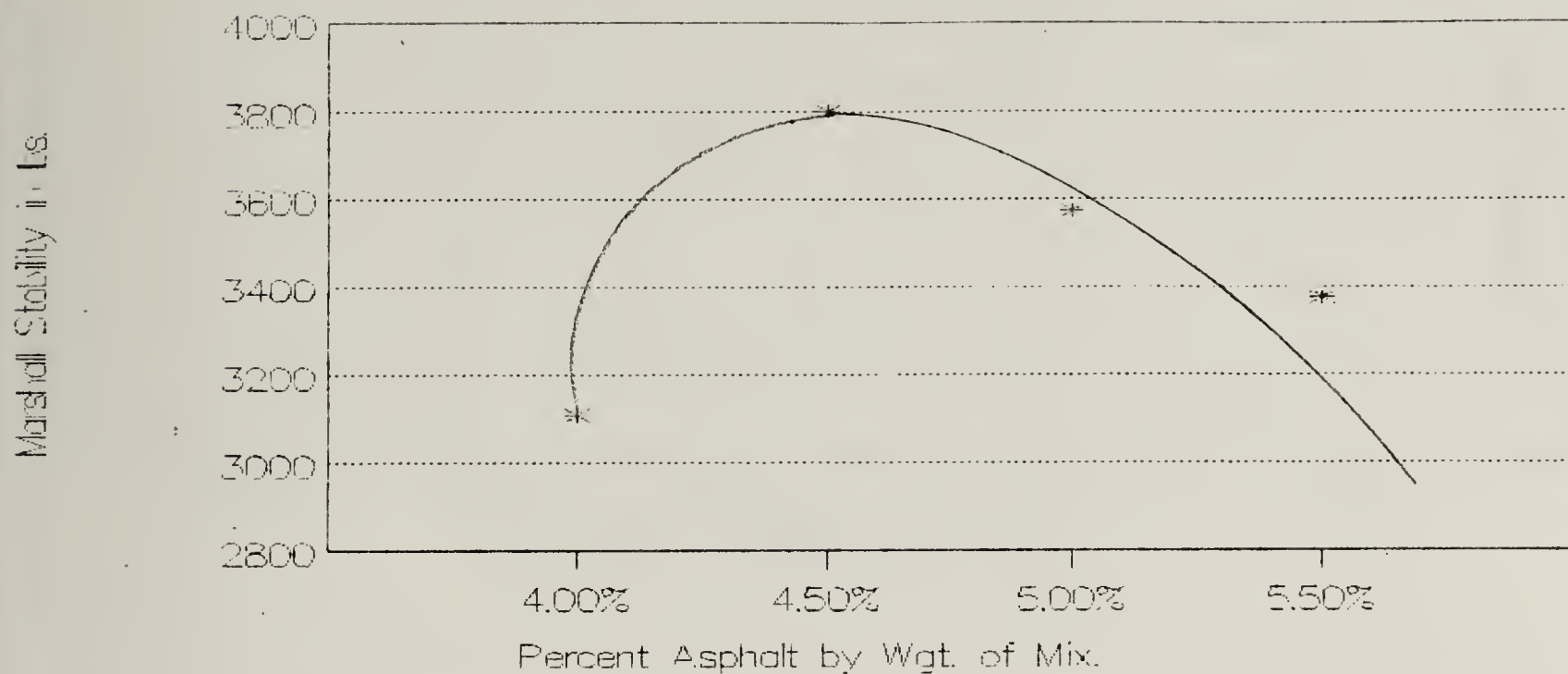
# Unmodified Conoco-4 in. Mold Specimen

Mineral Filler - Percent Air Voids.



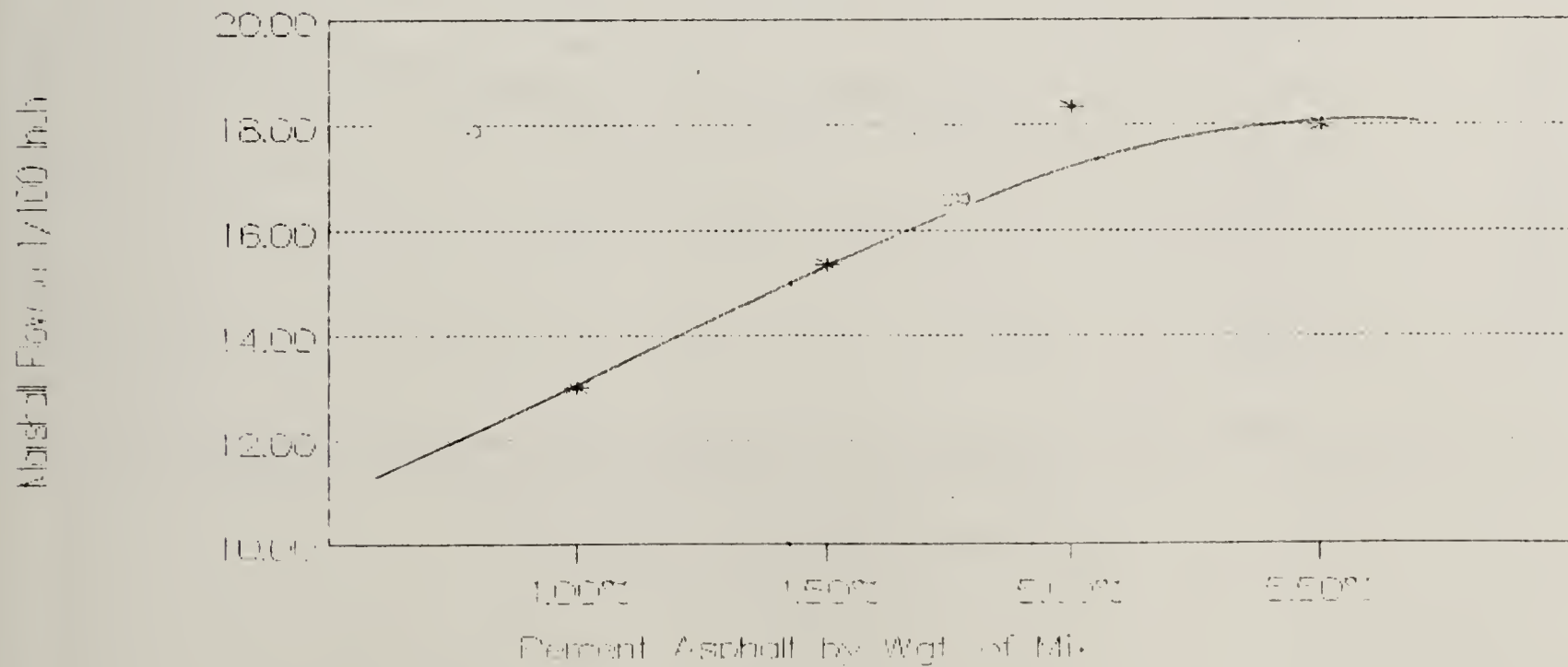
# Kraton Mod. Conoco — 4 in. Mold Specimen

## Mineral Filler — Marshall Stability.



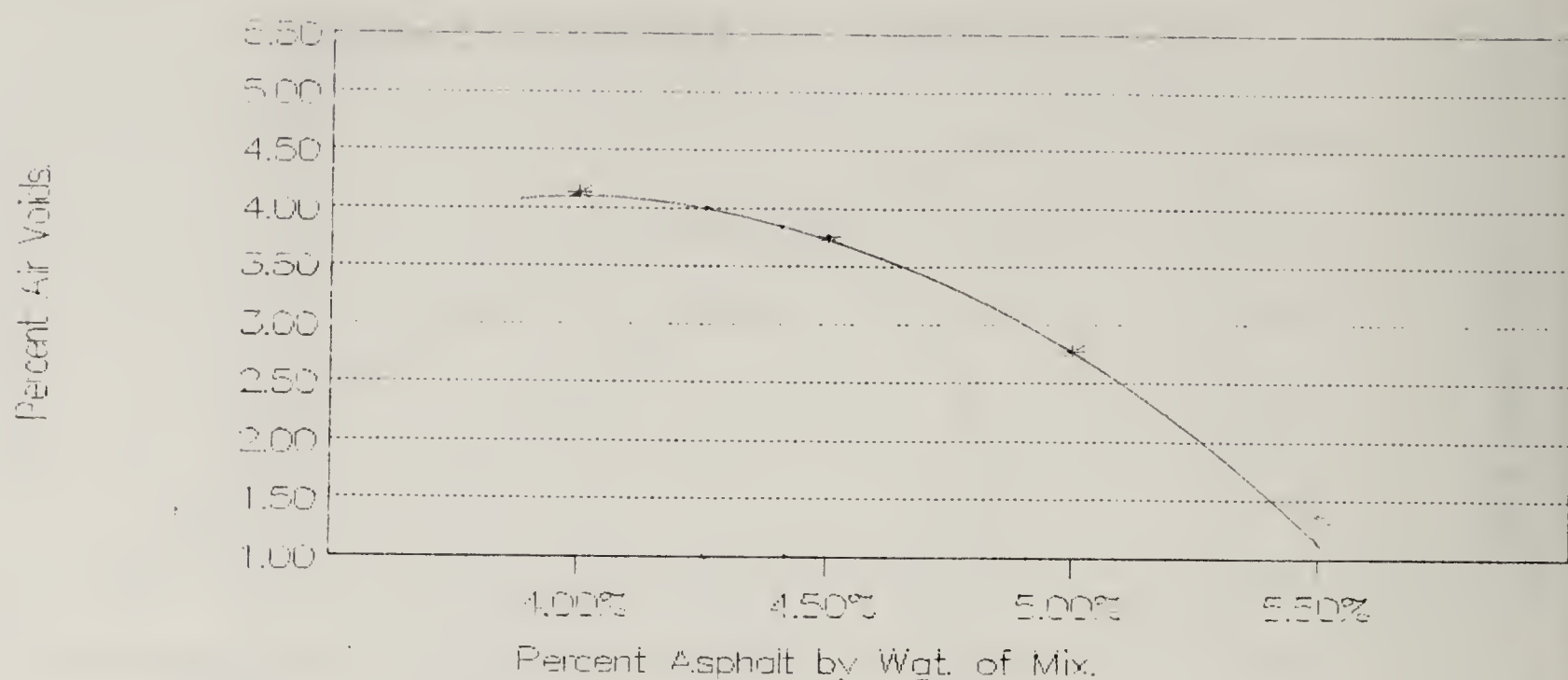
# Kraton Mod. Conoco — 4 in. Mold Specimen

## Mineral Filler — Marshall Flow.



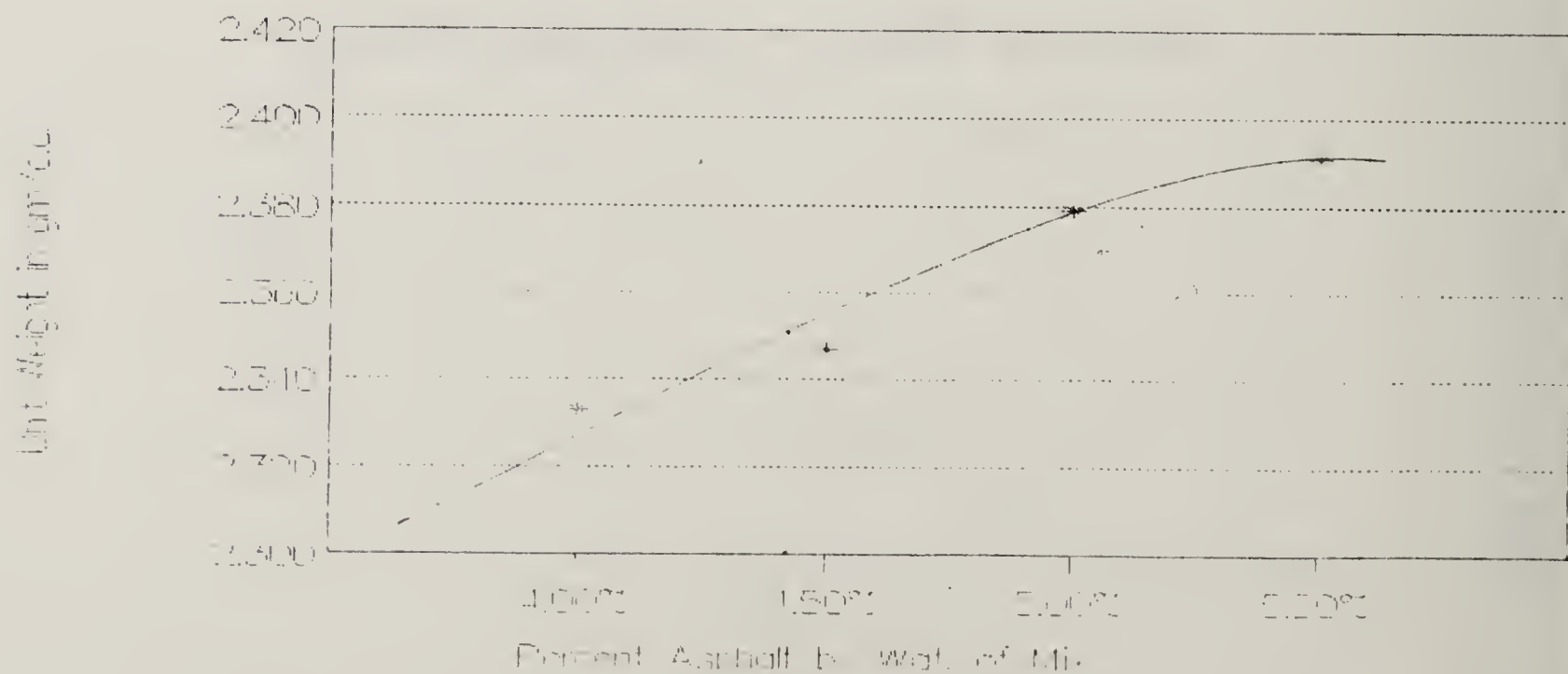
Kraton Mod. Conoco - 4 in. Mold Specimen

Mineral Filler - Percent Air Voids.

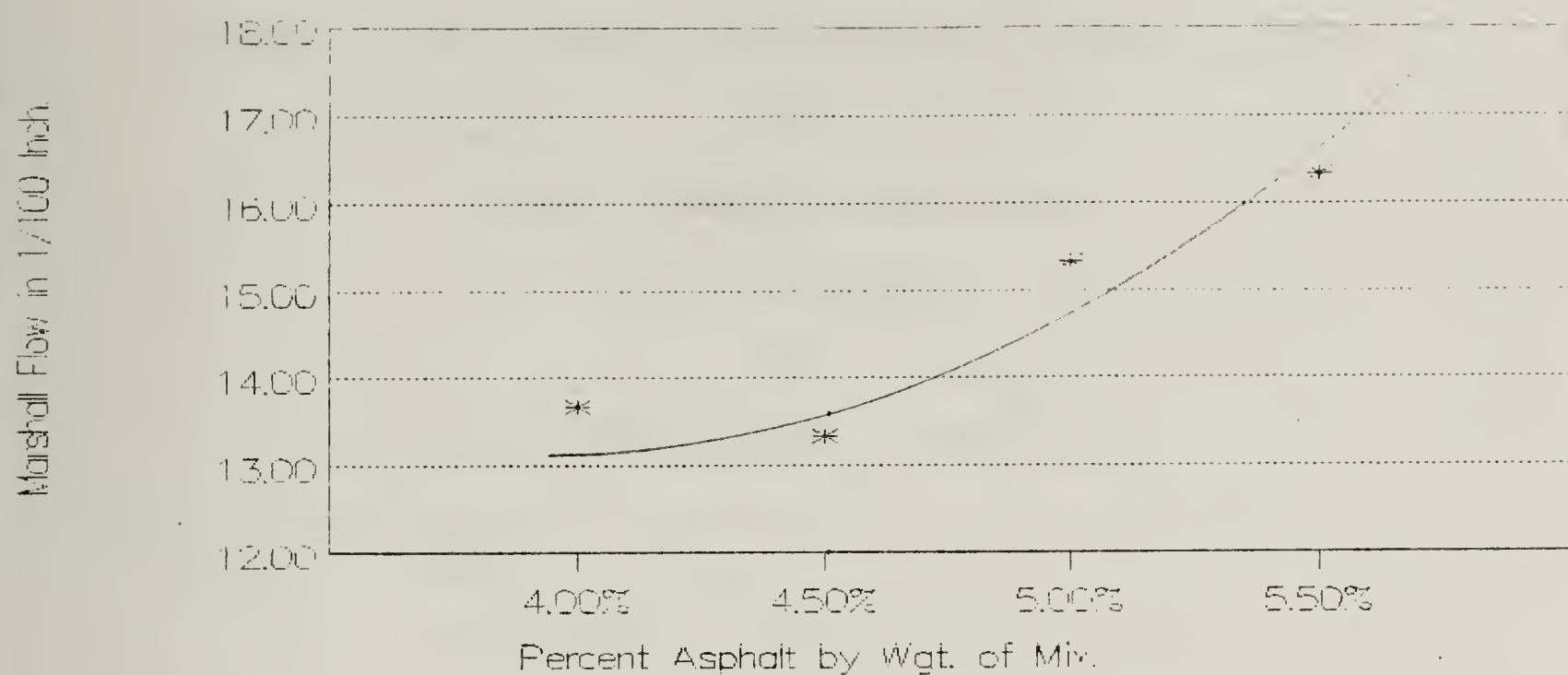


Kraton Mod. Conoco - 4 in. Mold Specimen

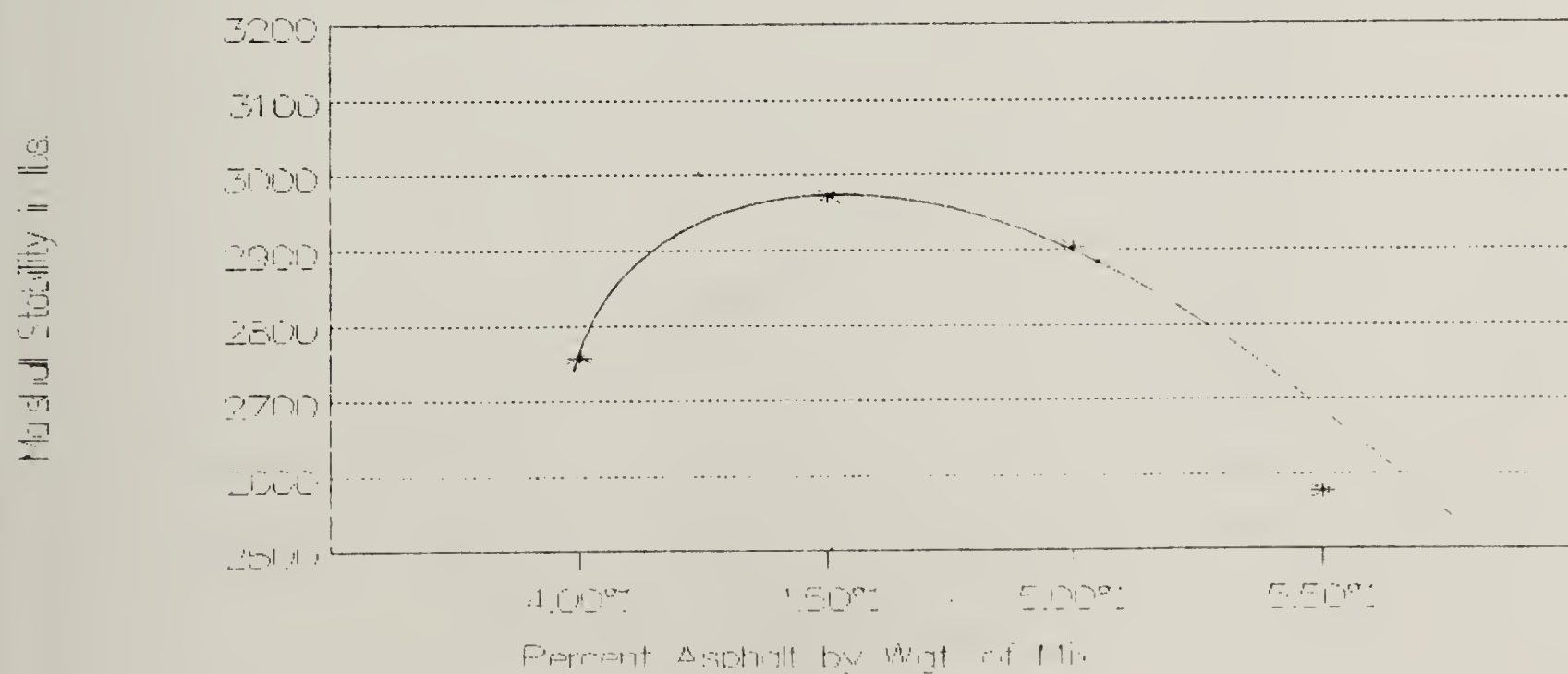
Mineral Filler - Unit Weight in gm/c.c.



# Polybilt Mod. Conoco 4 in. Mold Specimen Mineral Filler — Marshall Flow.

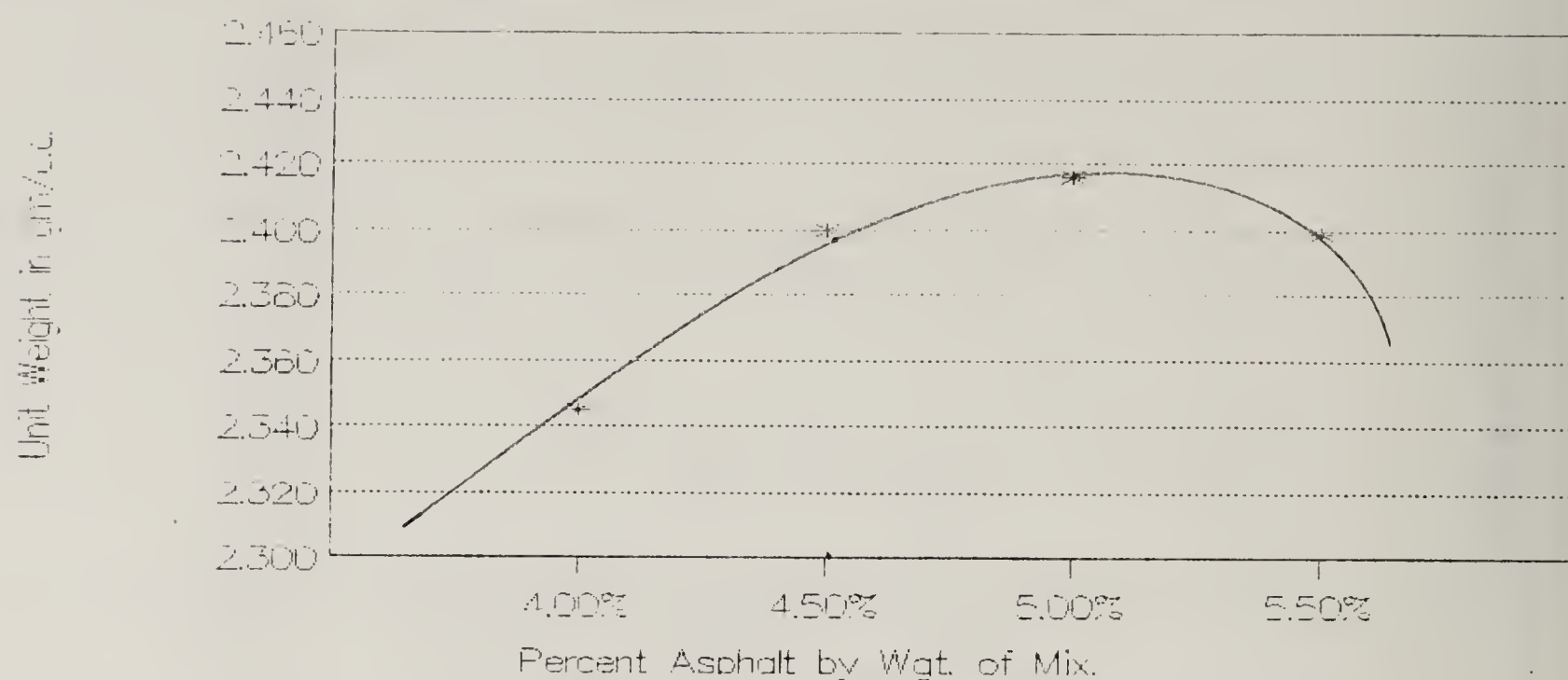


# Polybilt Mod. Conoco 4 in. Mold Specimen Mineral Filler — Marshall Stability.



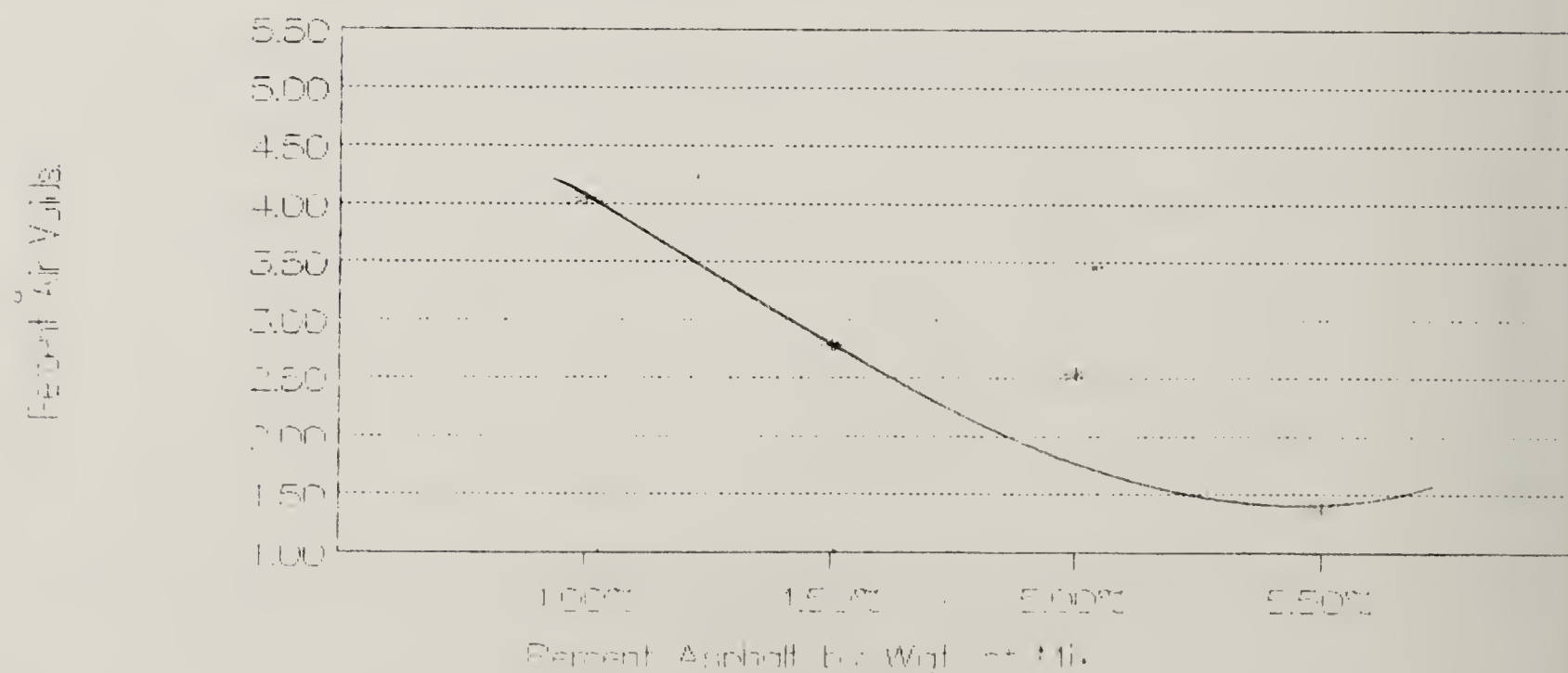
# Polybilt Mod. Conoco 4 in. Mold Specimen

Mineral Filler - Unit Weight in gm/c.c.



# Polybilt Mod. Conoco 4 in. Mold Specimen

Mineral Filler - Percent Air Voids.



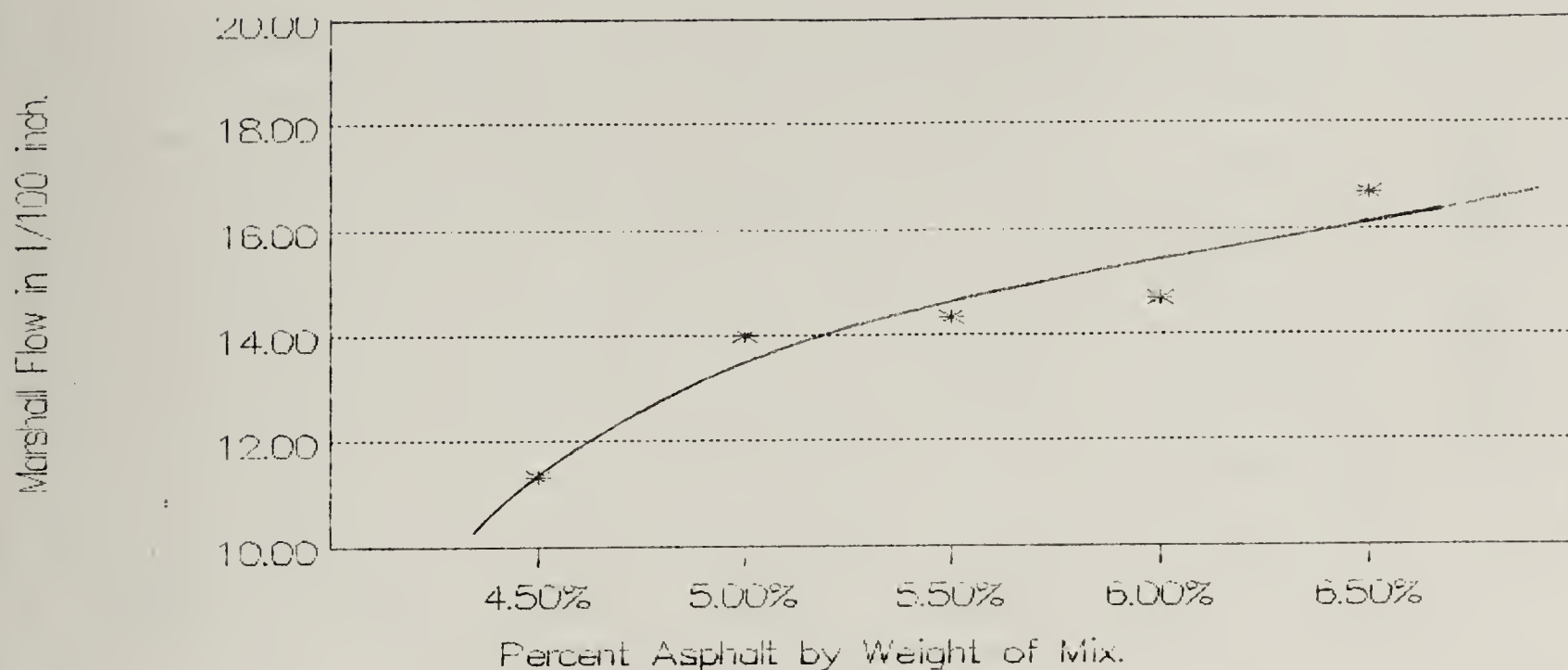
## Appendix B

Marshall Test Properties Curves for 6-inch Specimens  
with  
First Gradation Aggregates  
75 and 112 Blows  
and  
Mineral Filler 75 Blows



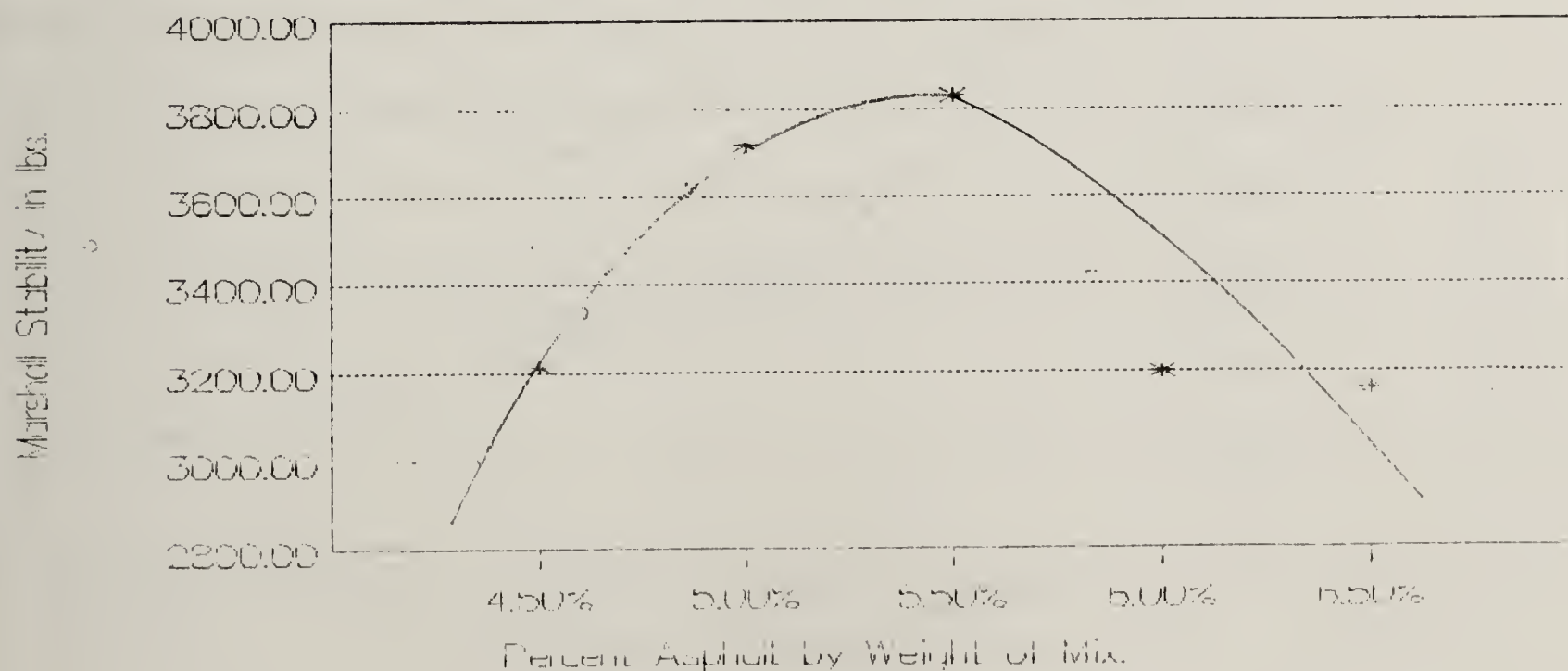
## Unmodified Cenex Marshall Flow.

I-Grad. without Selected Agg., 75-Blow.



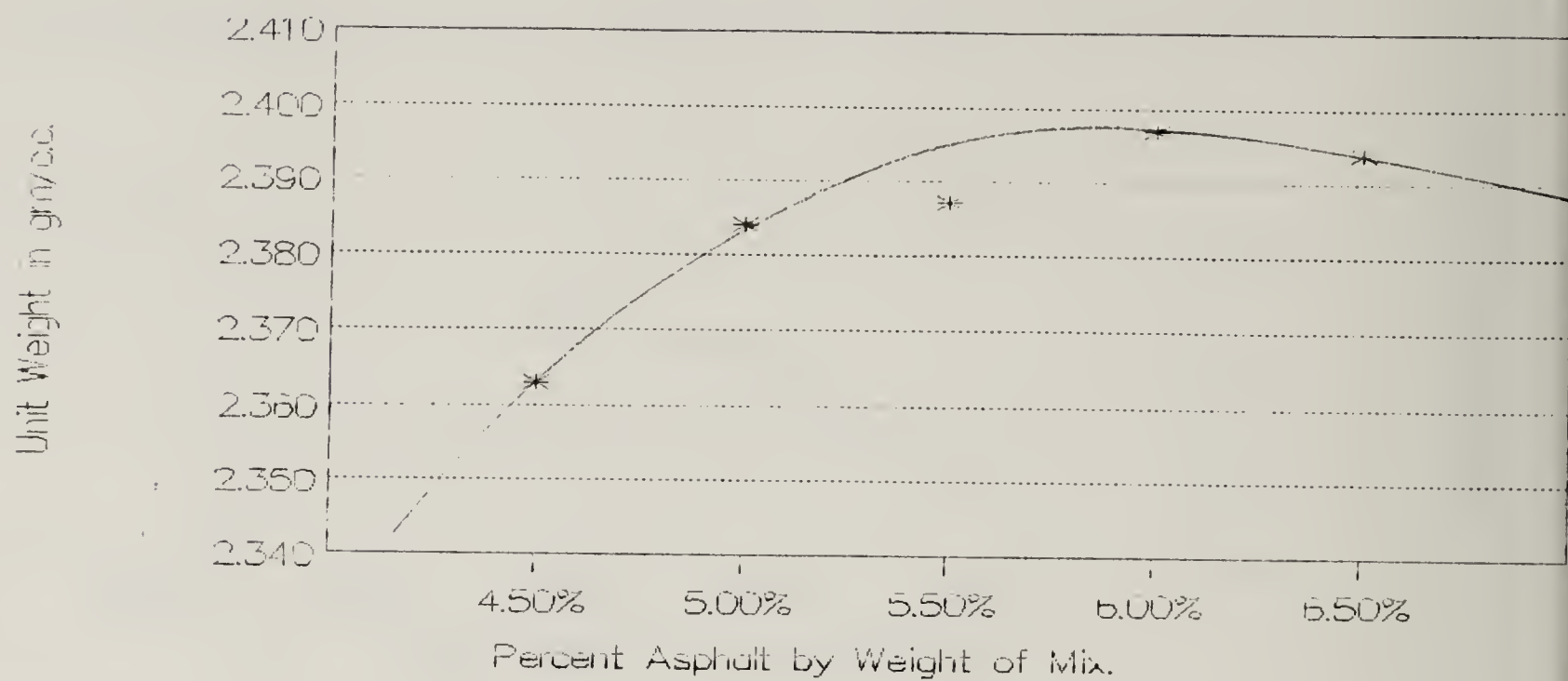
## Unmodified Cenex-Marshall Stability.

I-Grad. without Selected Agg., 75-Blow.



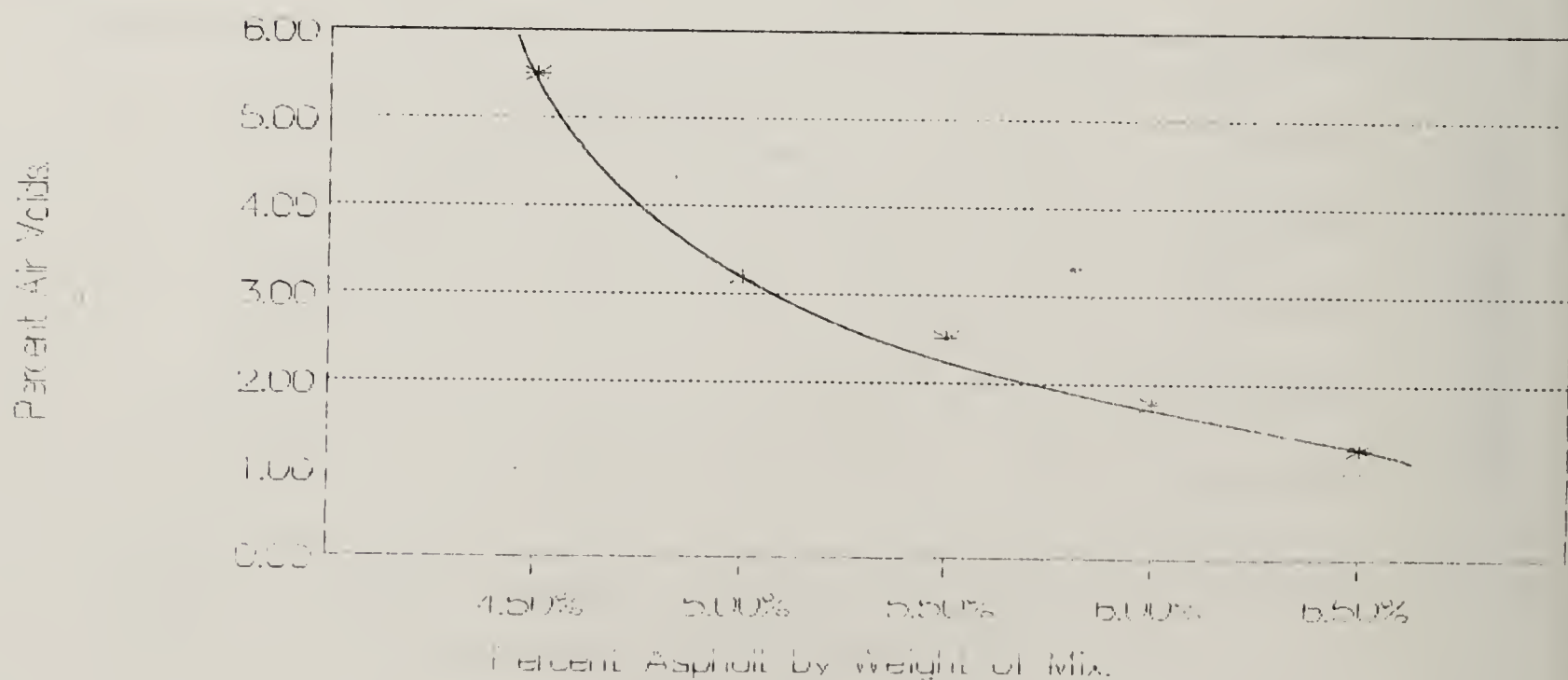
## Unmodified Cenex- Unit Weight in gm/cc.

I-Grad. without Selected Agg., 75-Blow.



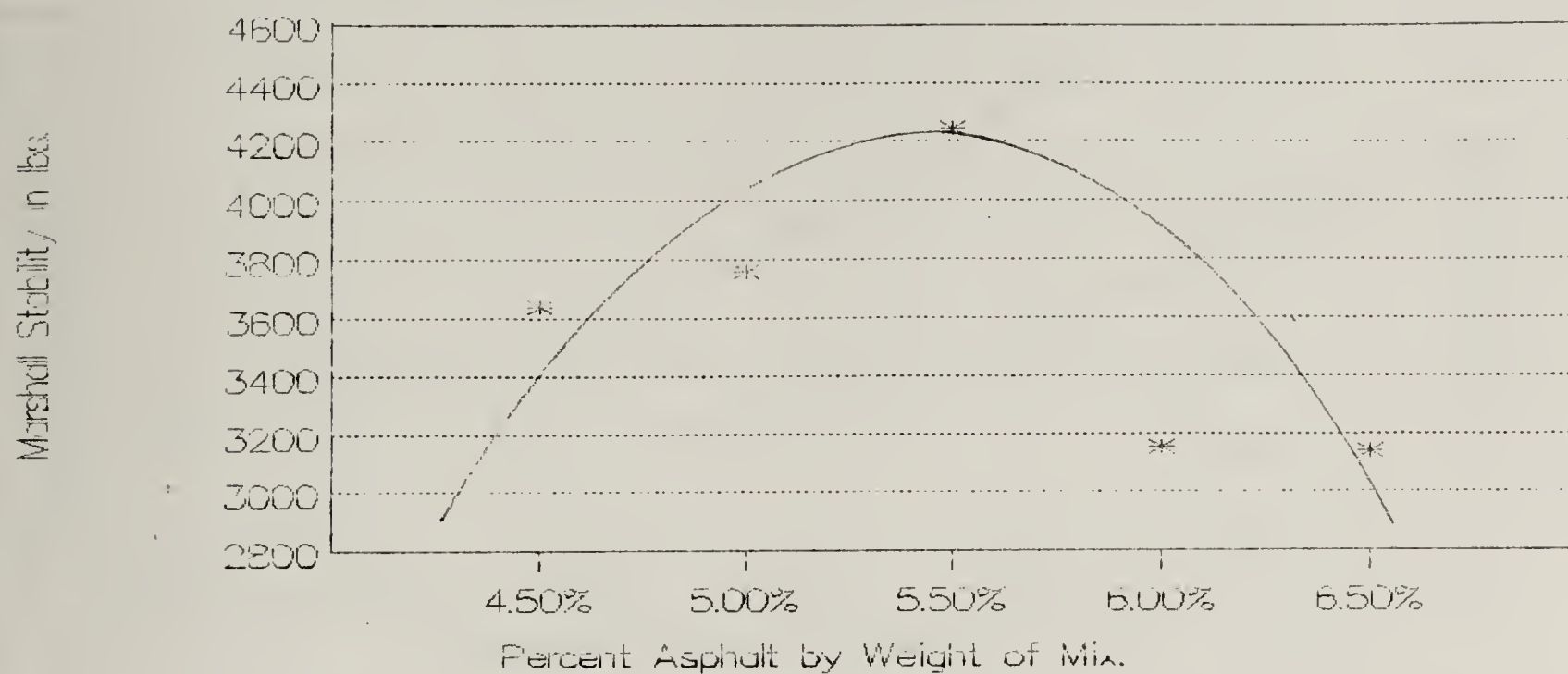
## Unmodified Cenex-Percent Air Voids.

I-Grad. without Selected Agg., 75-Blow.



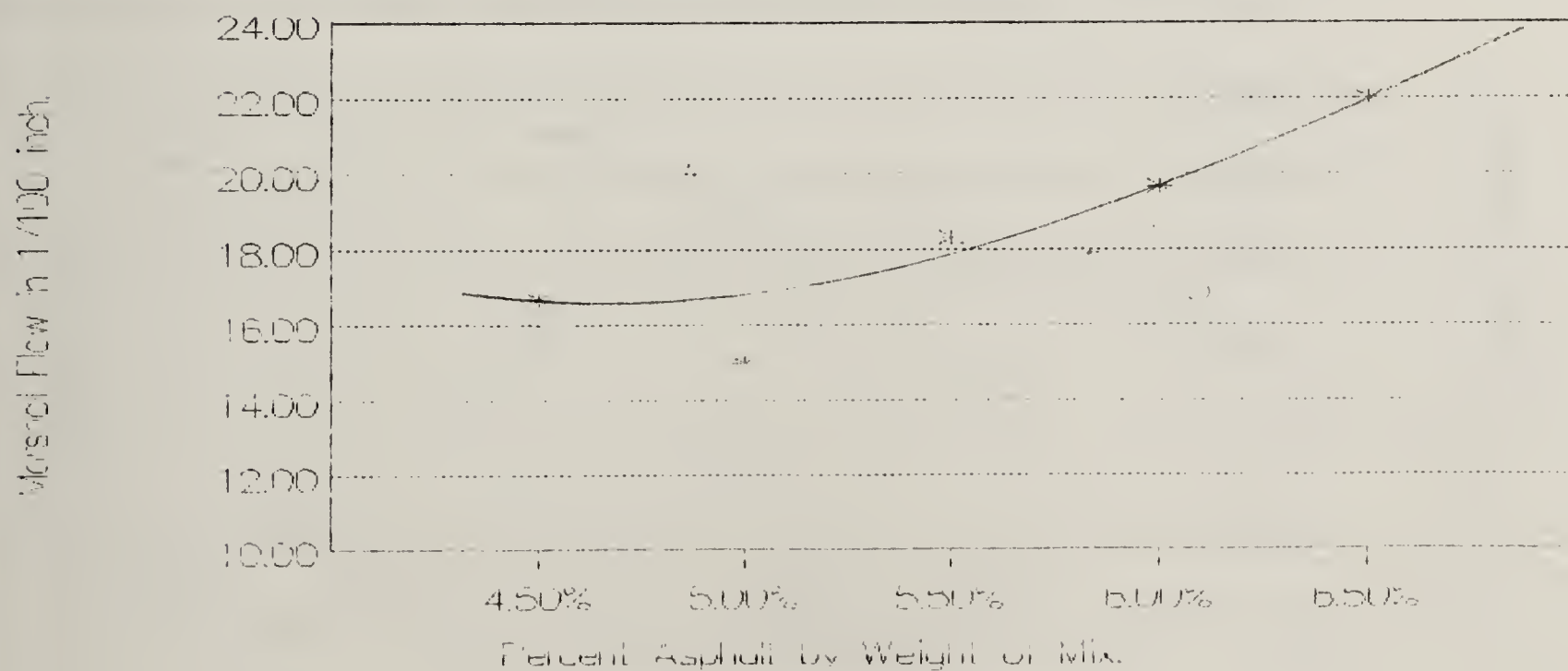
## Kraton Mod. Cenex Marshall Stability.

I-Grad. without Selected Agg., 75-Blow.



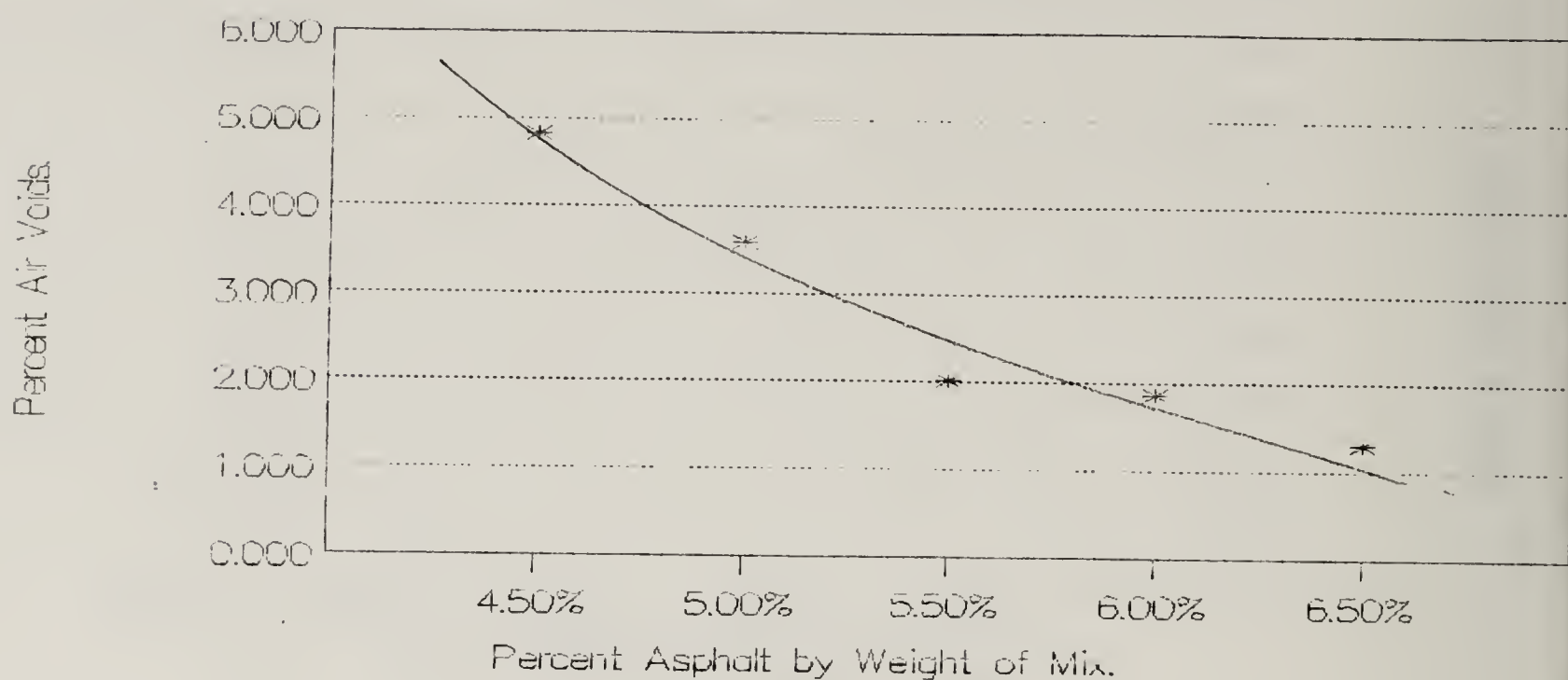
## Kraton Mod. Cenex-Marshall Flow.

I-Grad. without Selected Agg., 75-Blow.



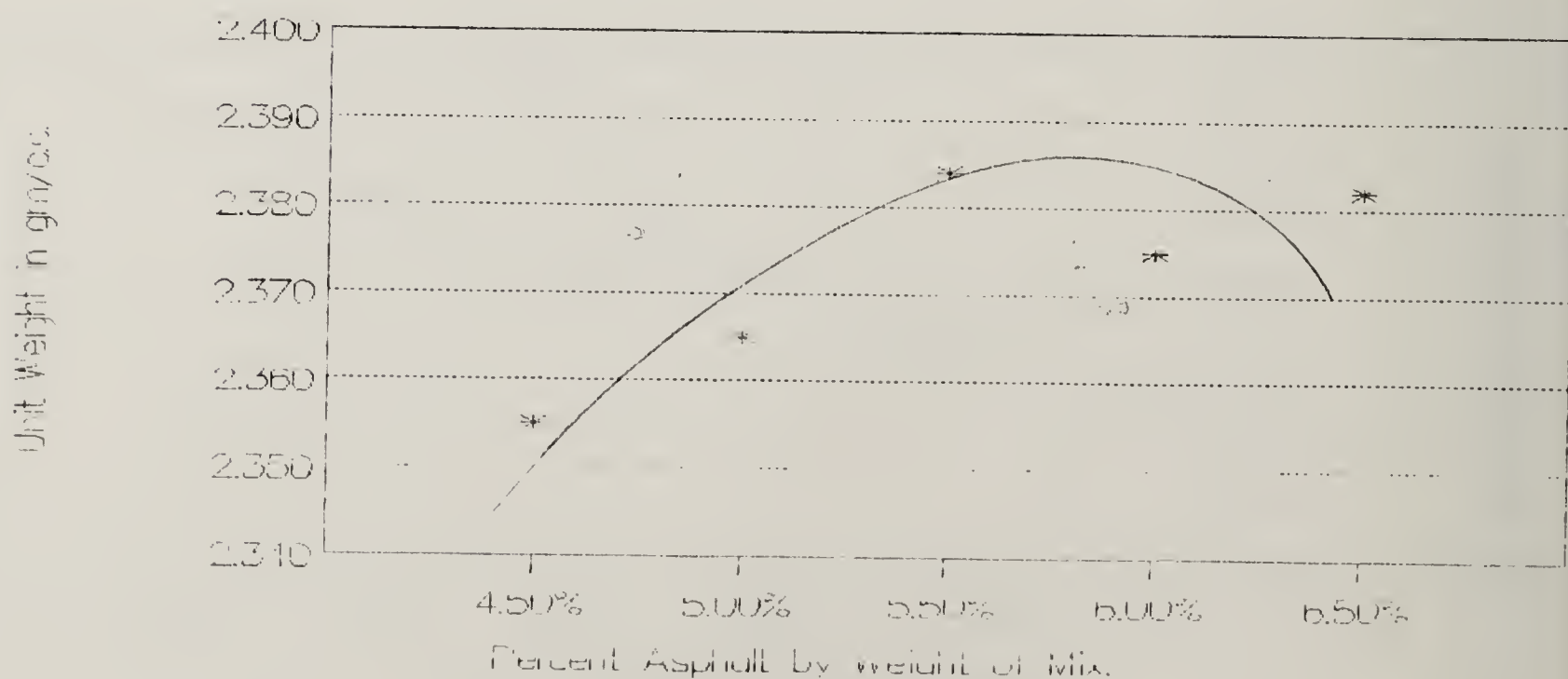
# Kraton Mod. Cenex—Percent Air Voids.

I-Grad. without Selected Agg., 75-Blow.



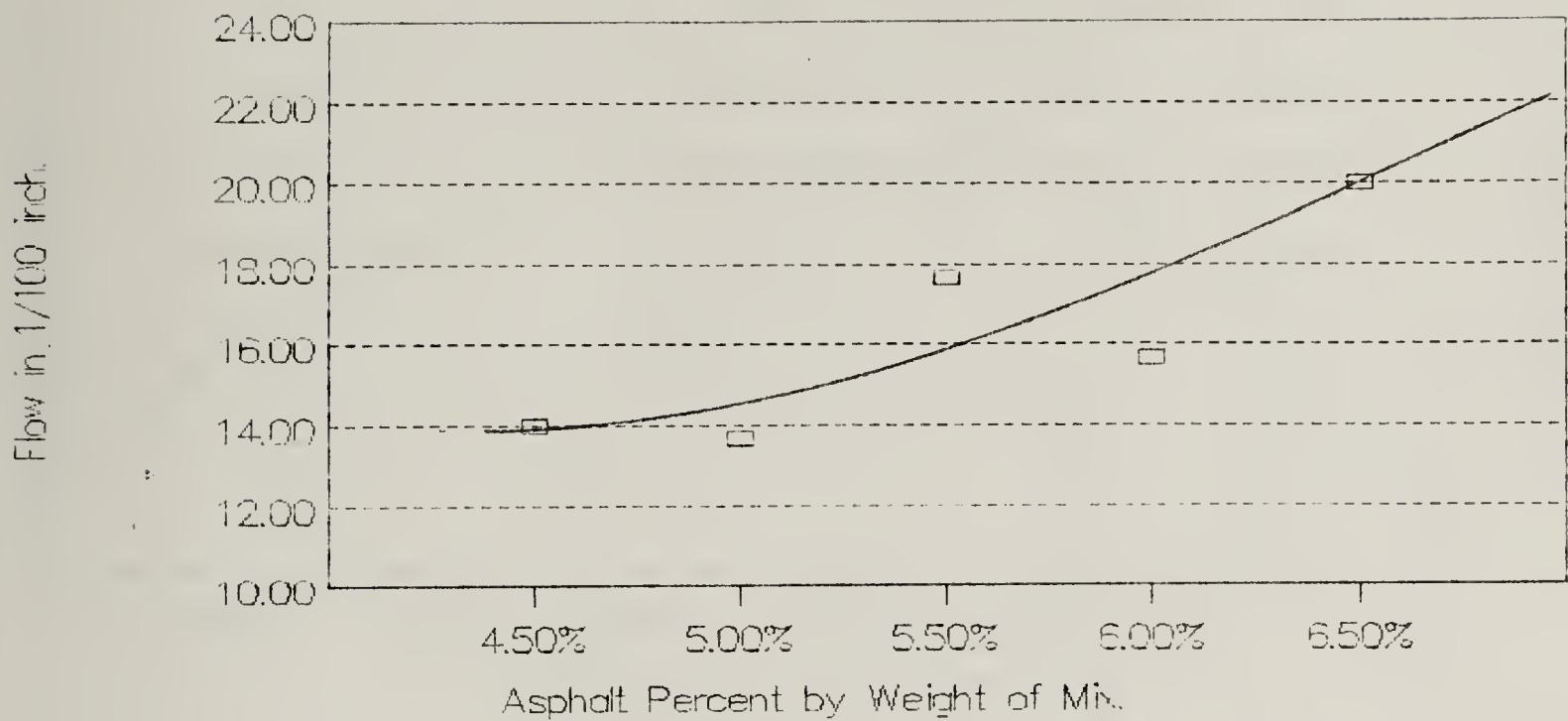
# Kraton Mod. Cenex—Unit Weight in gm/cc

I-Grad. without Selected Agg., 75-Blow.



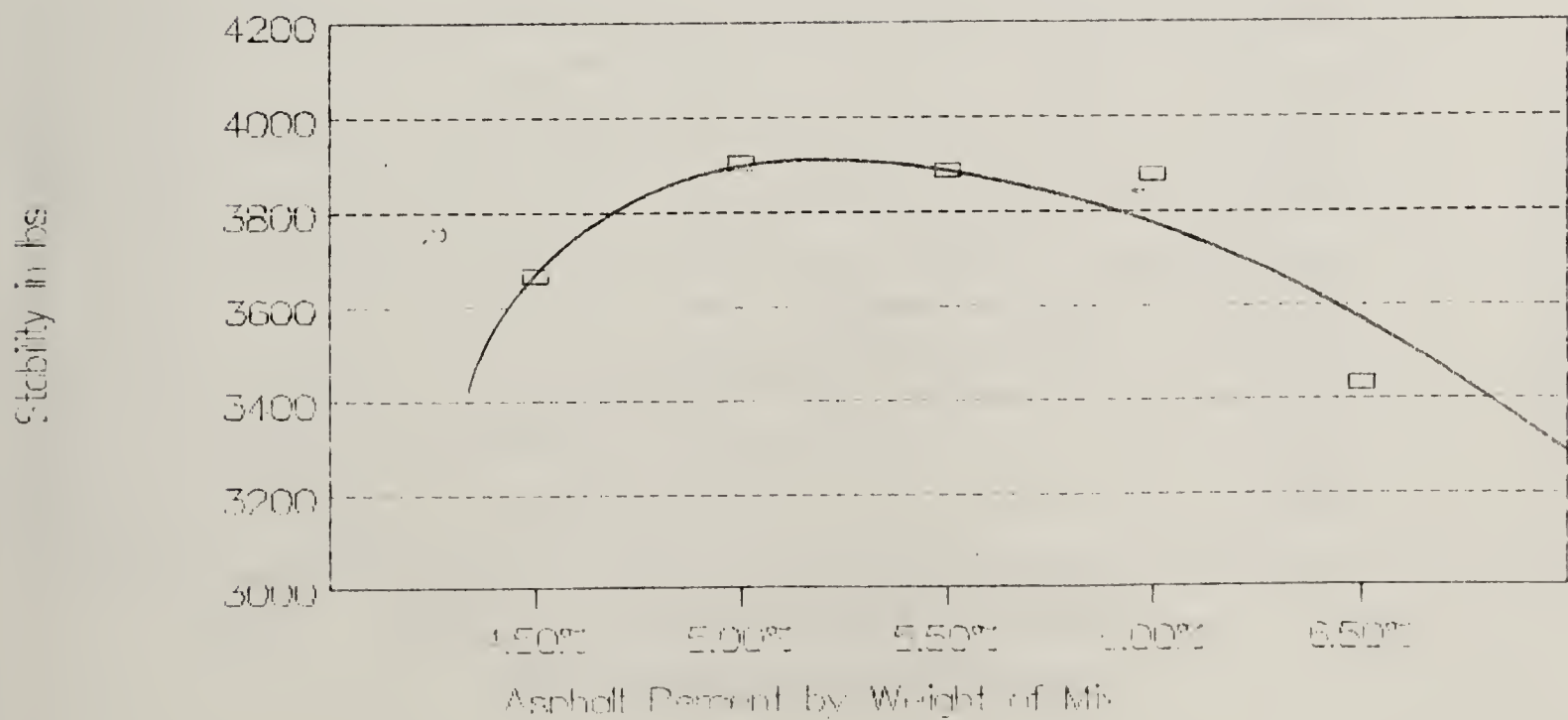
## Polybilt Mod. Cenex—Flow

I-Grad. without Selected Agg., 75-Blow.



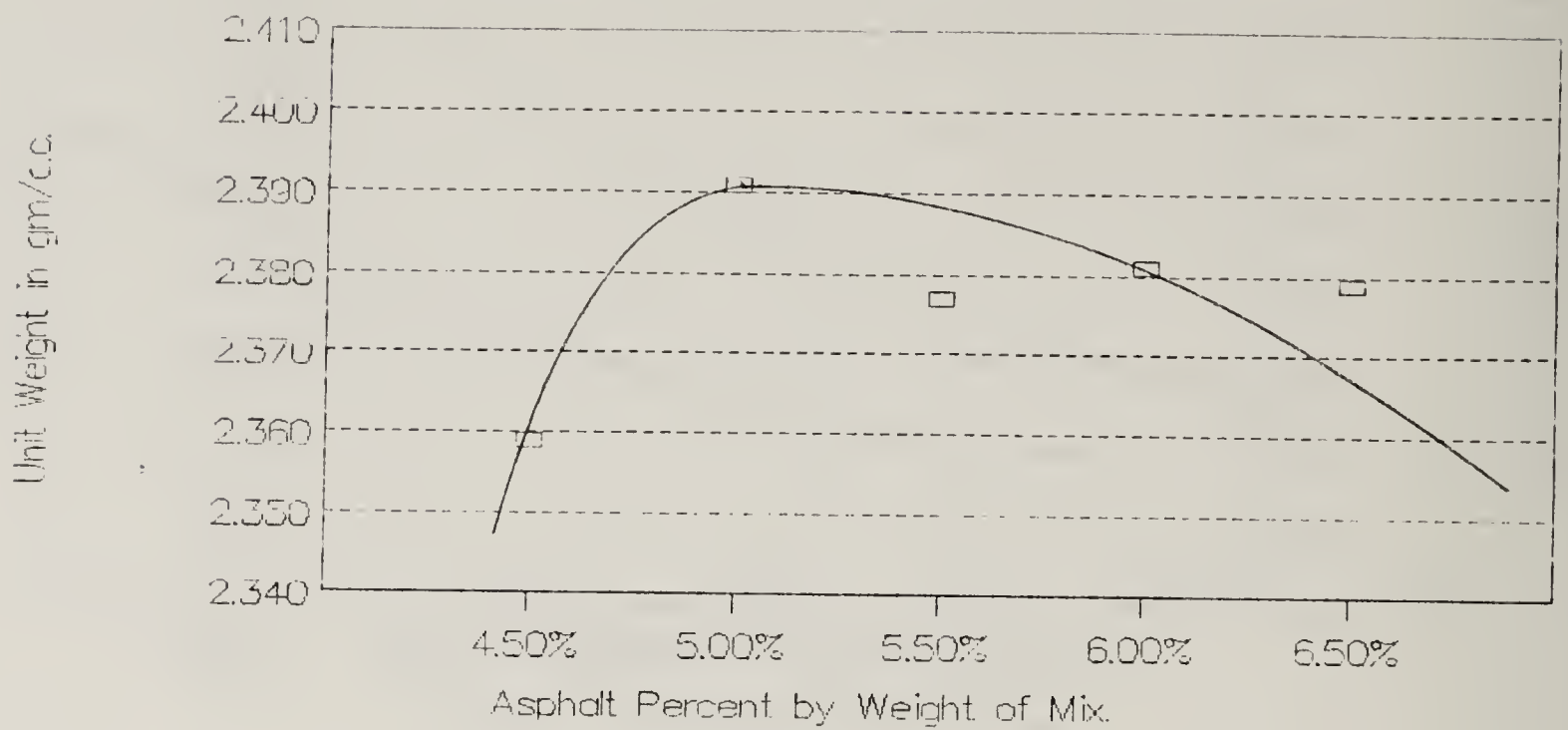
## Polybilt Mod. Cenex—Stability

I-Grad. without Selected Agg., 75-Blow.



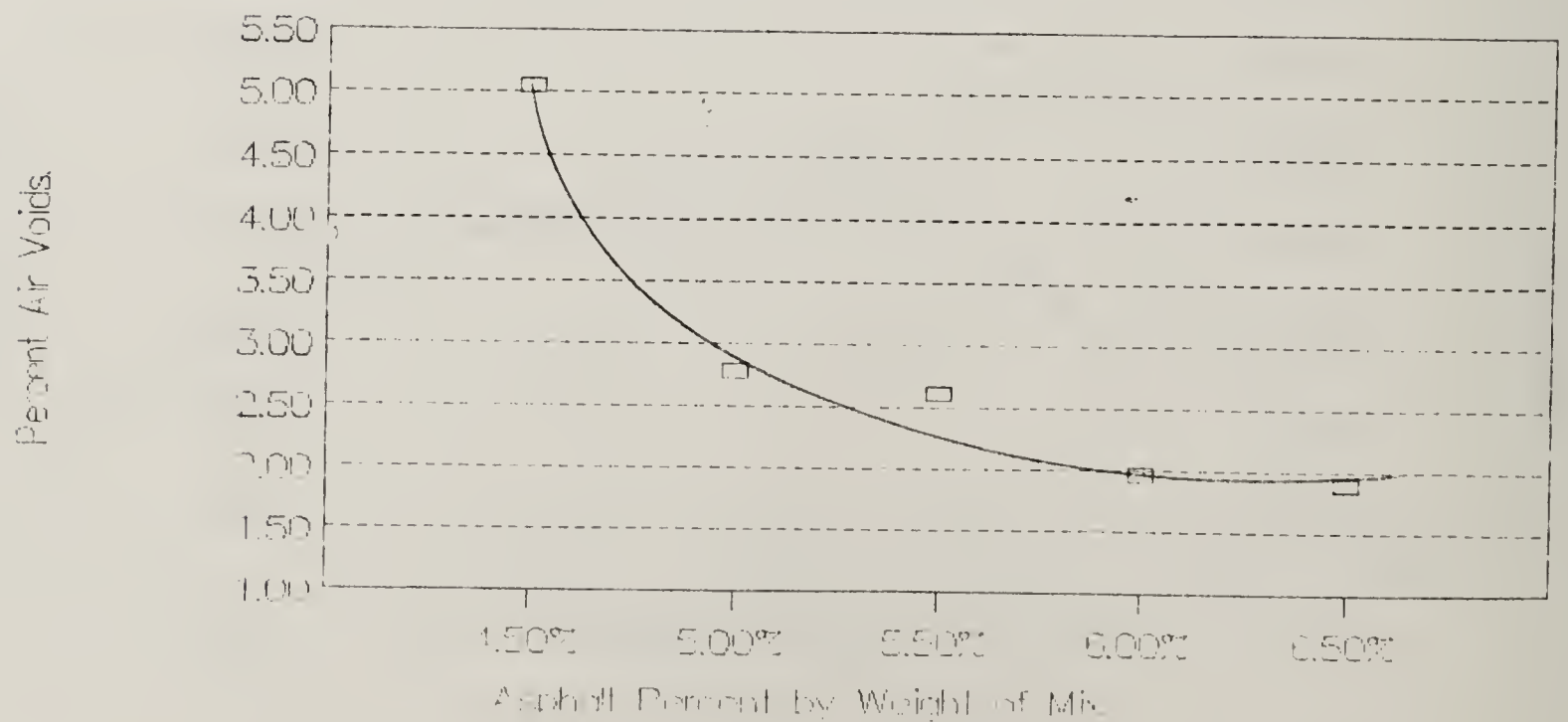
## Polybilt Mod. Cenex—Unit Weight

I-Grad. without Selected Agg., 75-Blow.



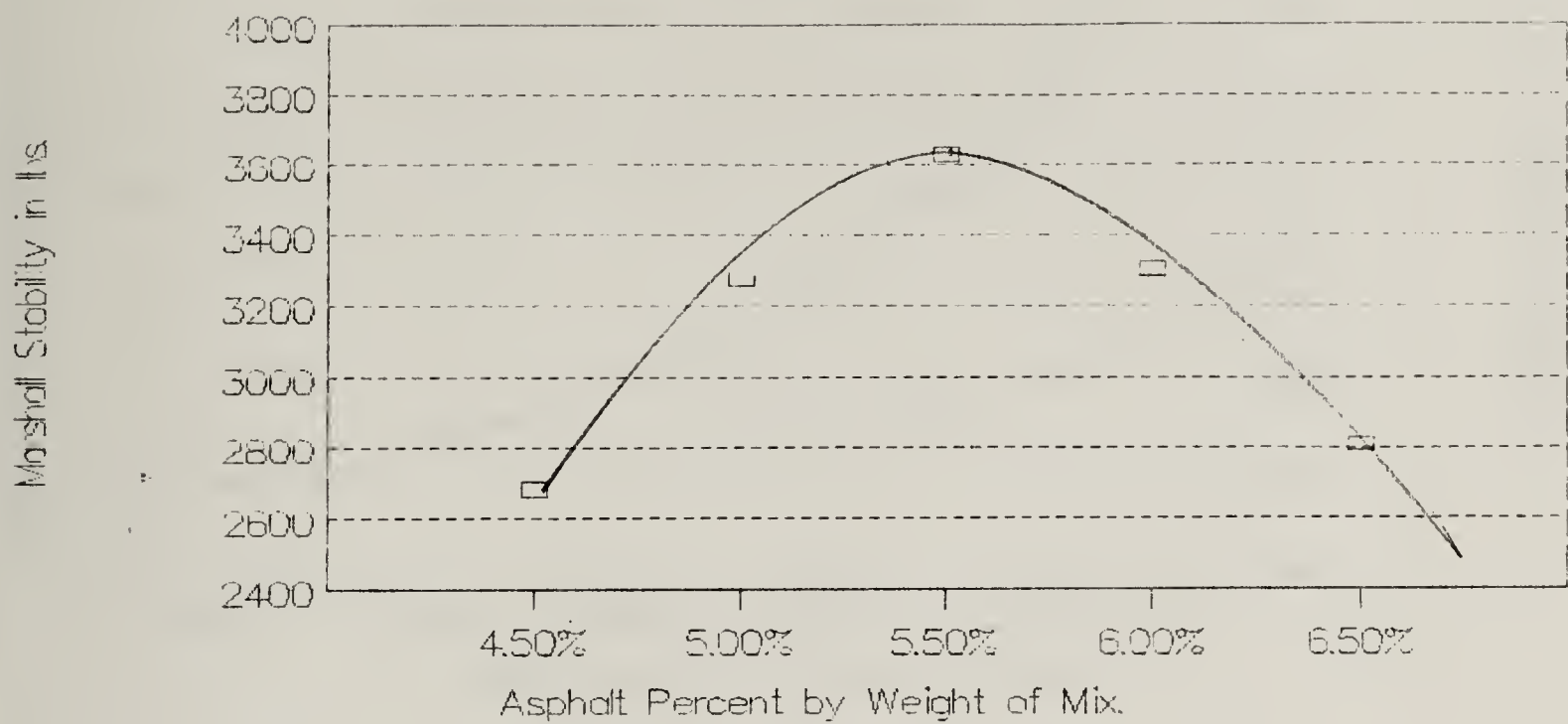
## Polybilt Mod. Cenex—Air Voids

I-Grad. without Selected Agg., 75-Blow.



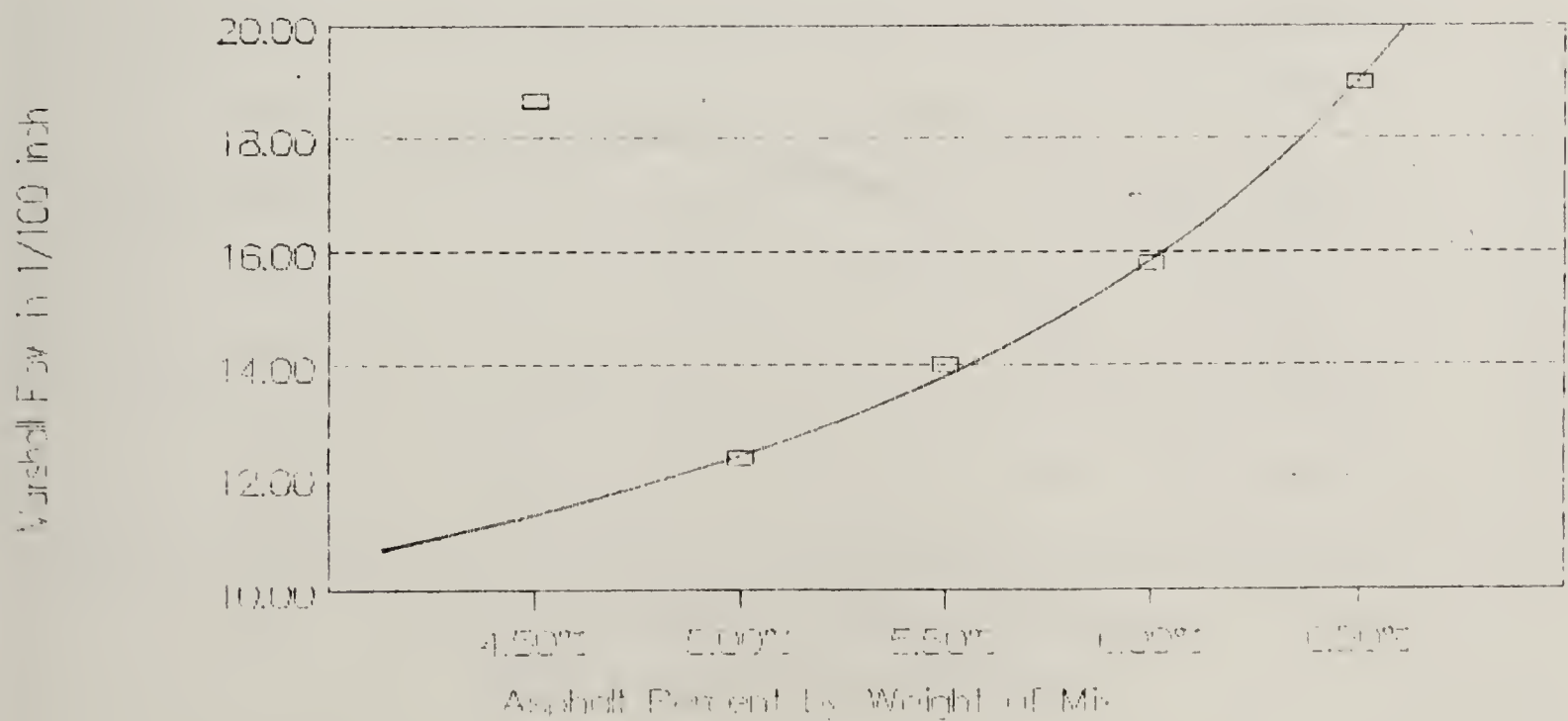
## Unmodified Conoco-Stability

I-Grad. without Selected Agg., 75-Blow.



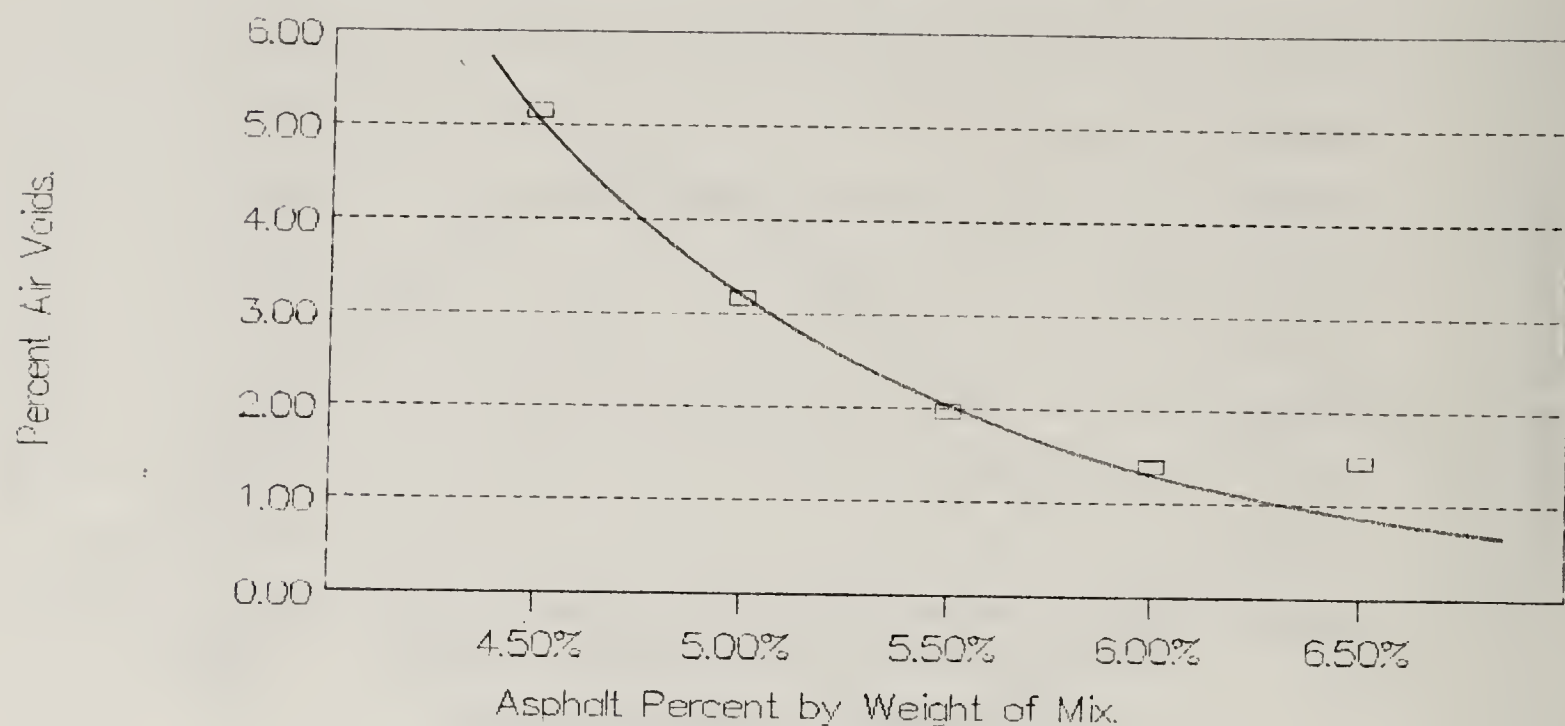
## Unmodified Conoco-Flow

I-Grad. without Selected Agg., 75-Blow.



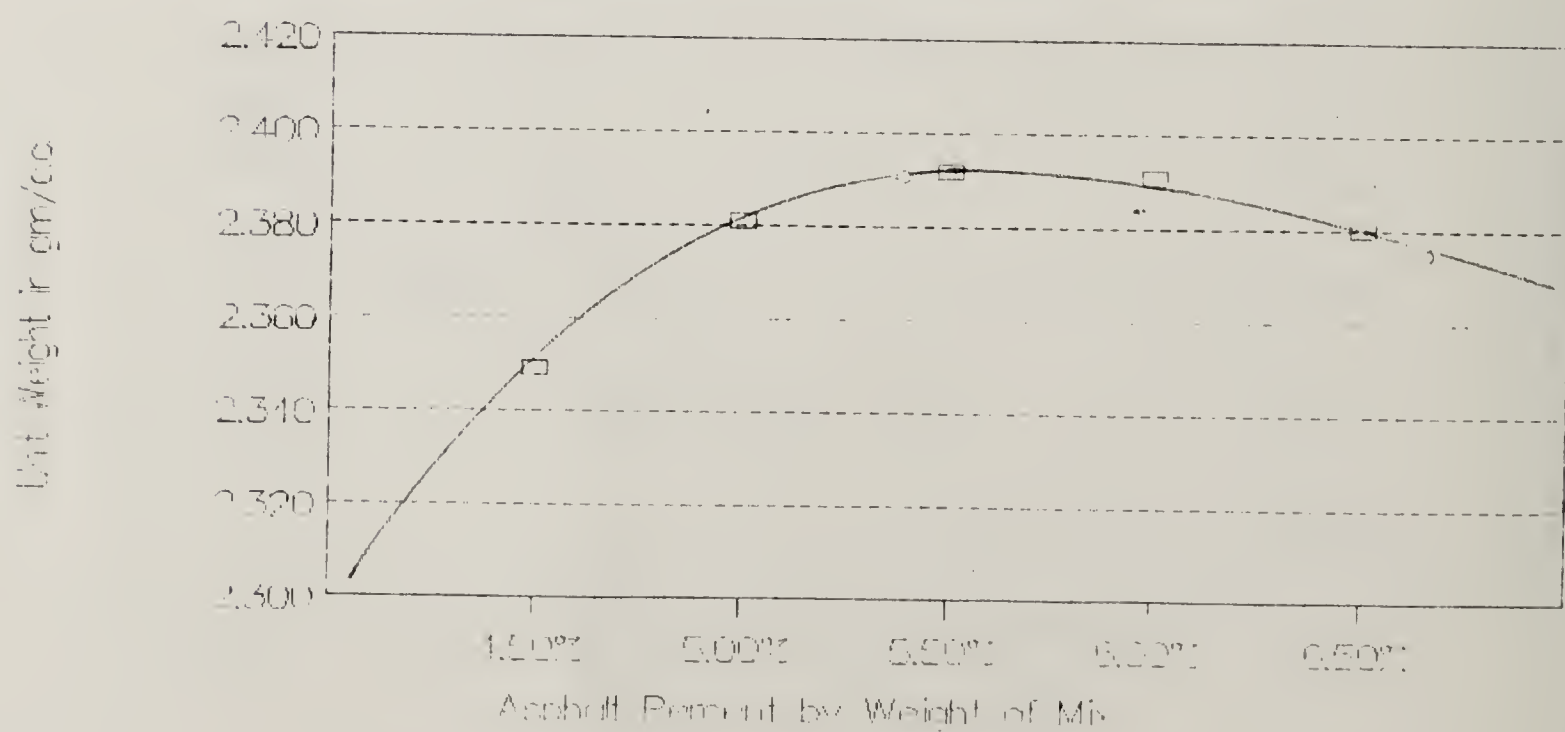
## Unmodified Conoco—Percent Air Voids.

I-Grad. without Selected Agg., 75-Blow.



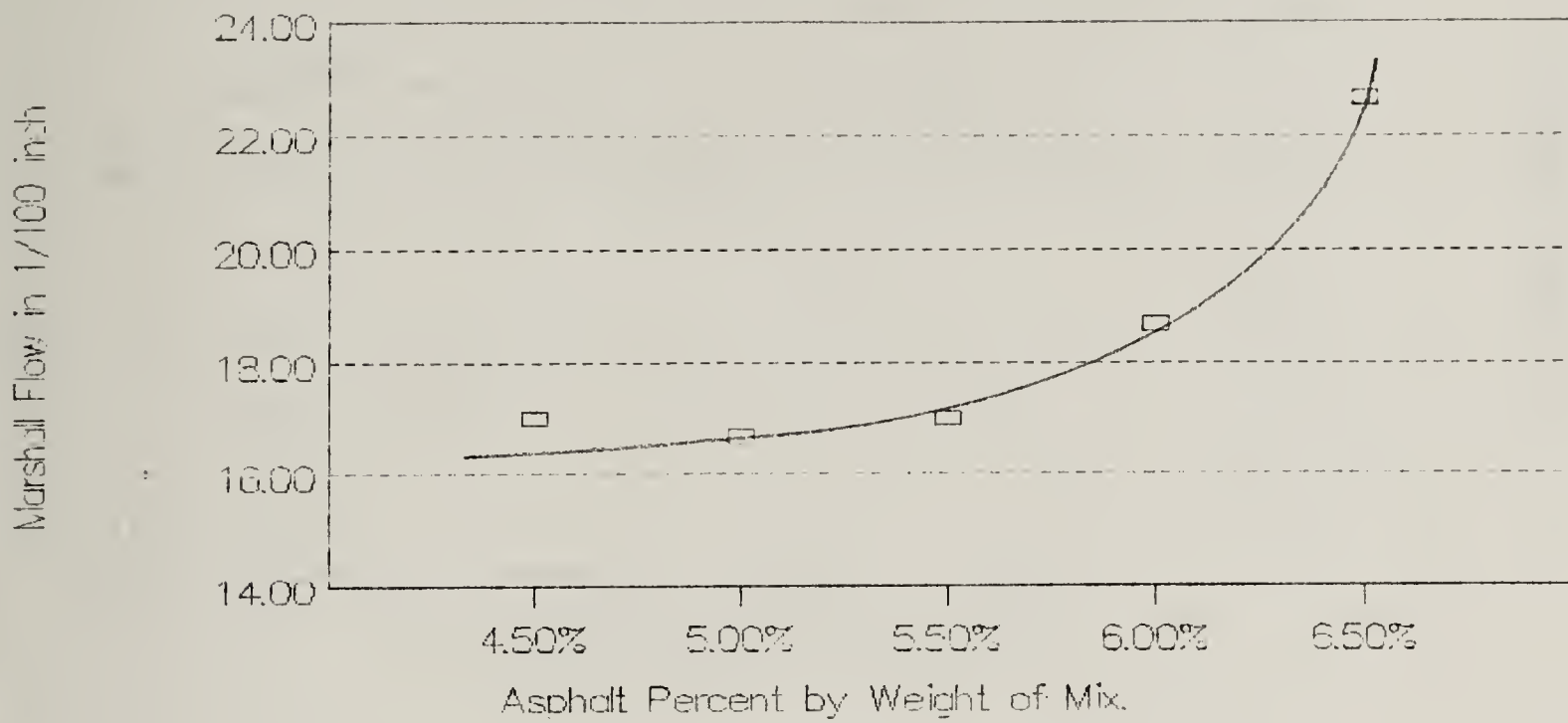
## Unmodified Conoco—Unit Weight

I-Grad. without Selected Agg., 75-Blow.



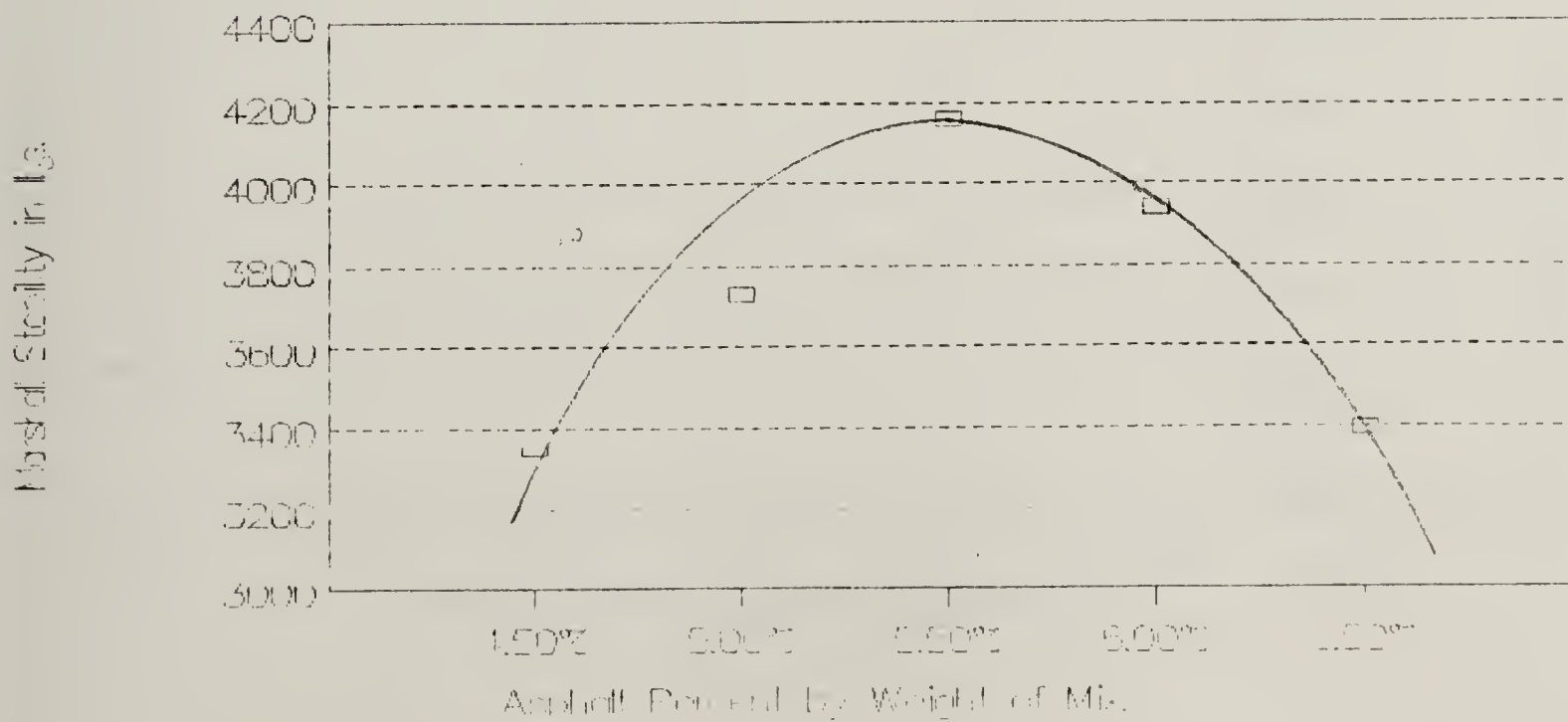
## Kraton Mod. Conoco-Flow

I-Grad. without Selected Agg., 75-Blow.



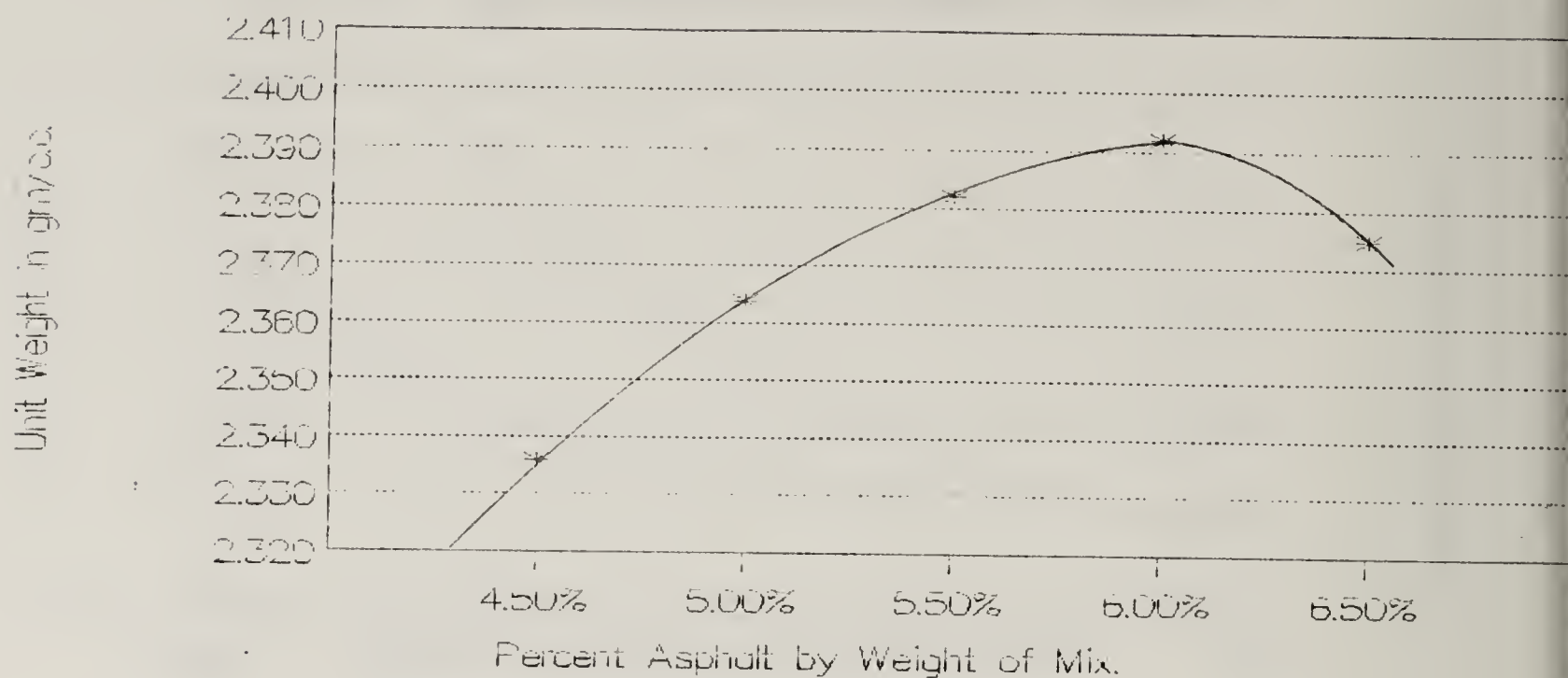
## Kraton Mod. Conoco-Stability

I-Grad. without Selected Agg., 75-Blow.



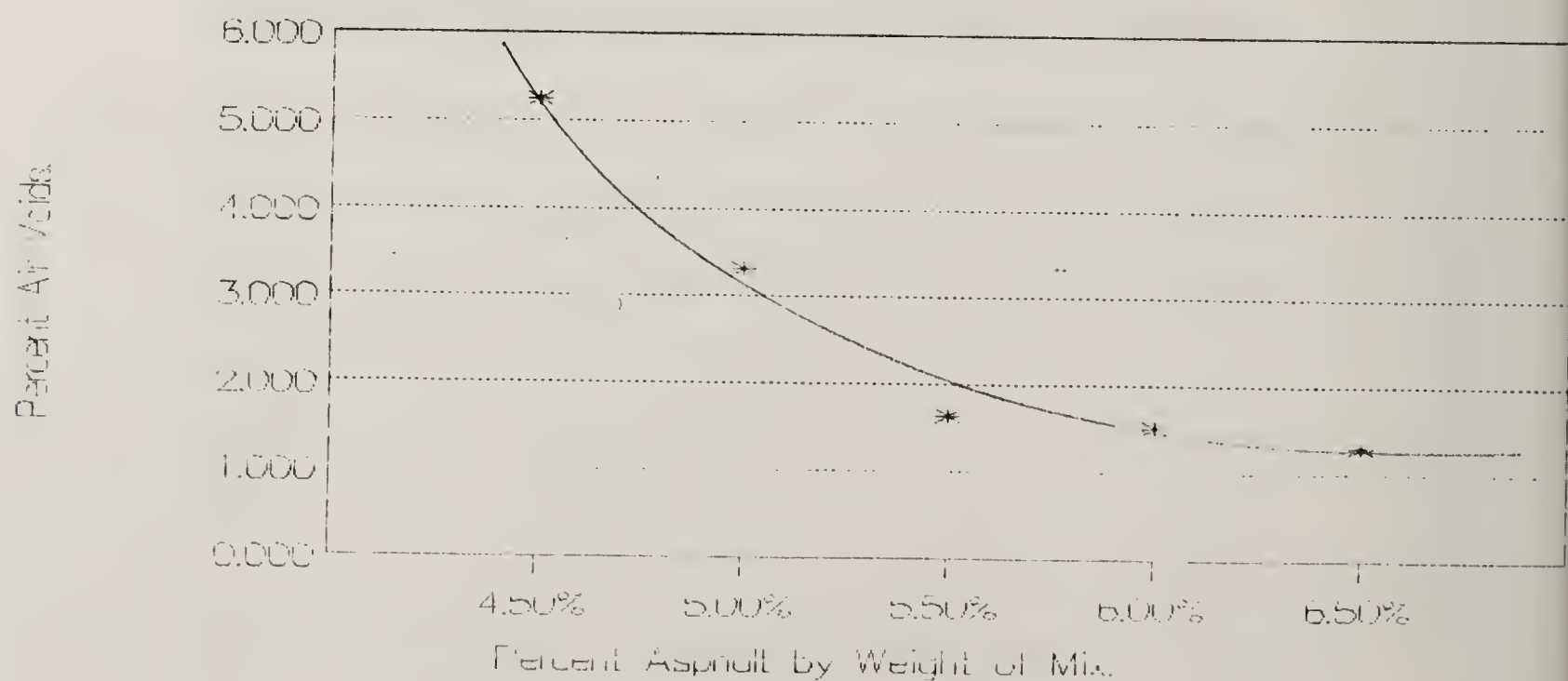
## Kraton Mod. Conoco-Unit Weight

I-Grad. without Selected Agg., 75-Blow.



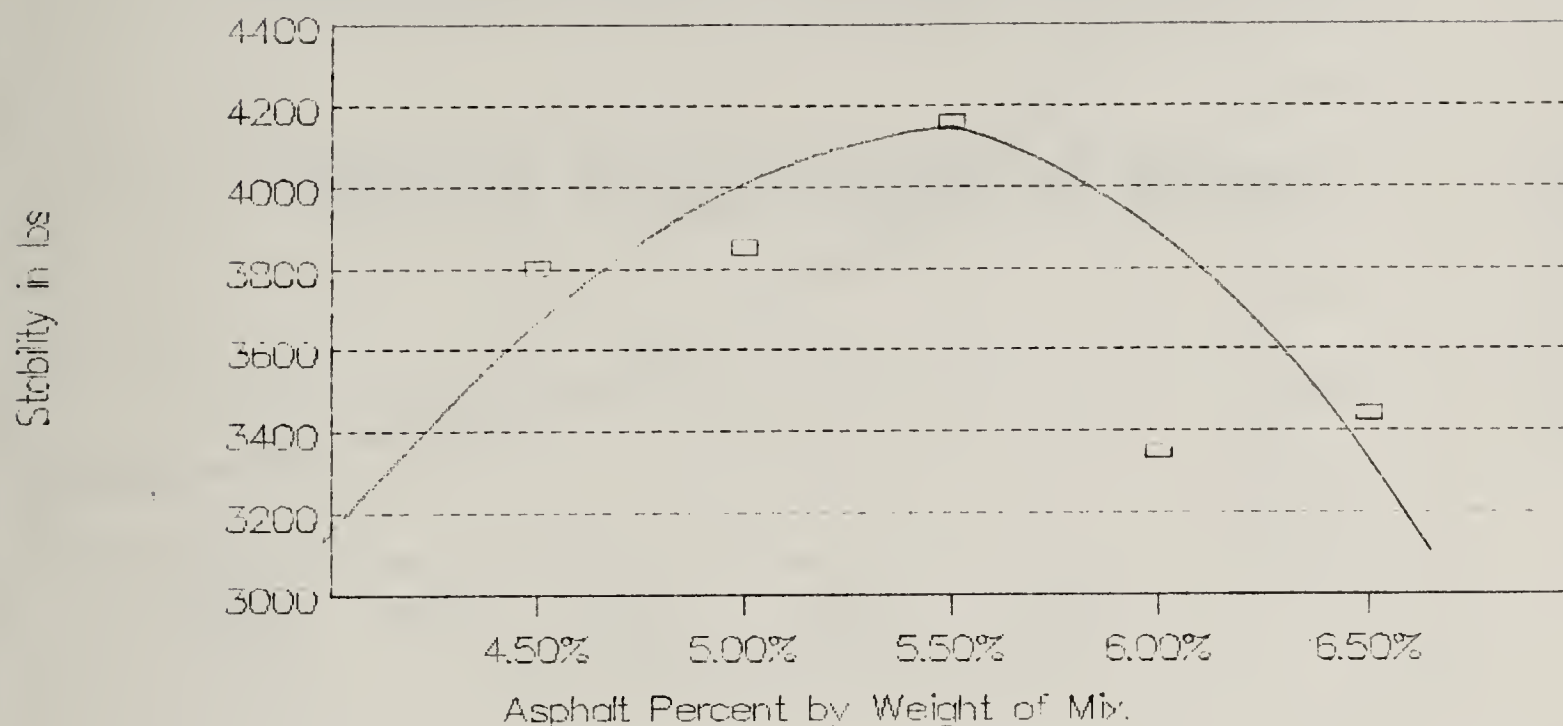
## Kraton Mod. Conoco-Percent Air Voids.

I-Grad. without Selected Agg., 75-Blow.



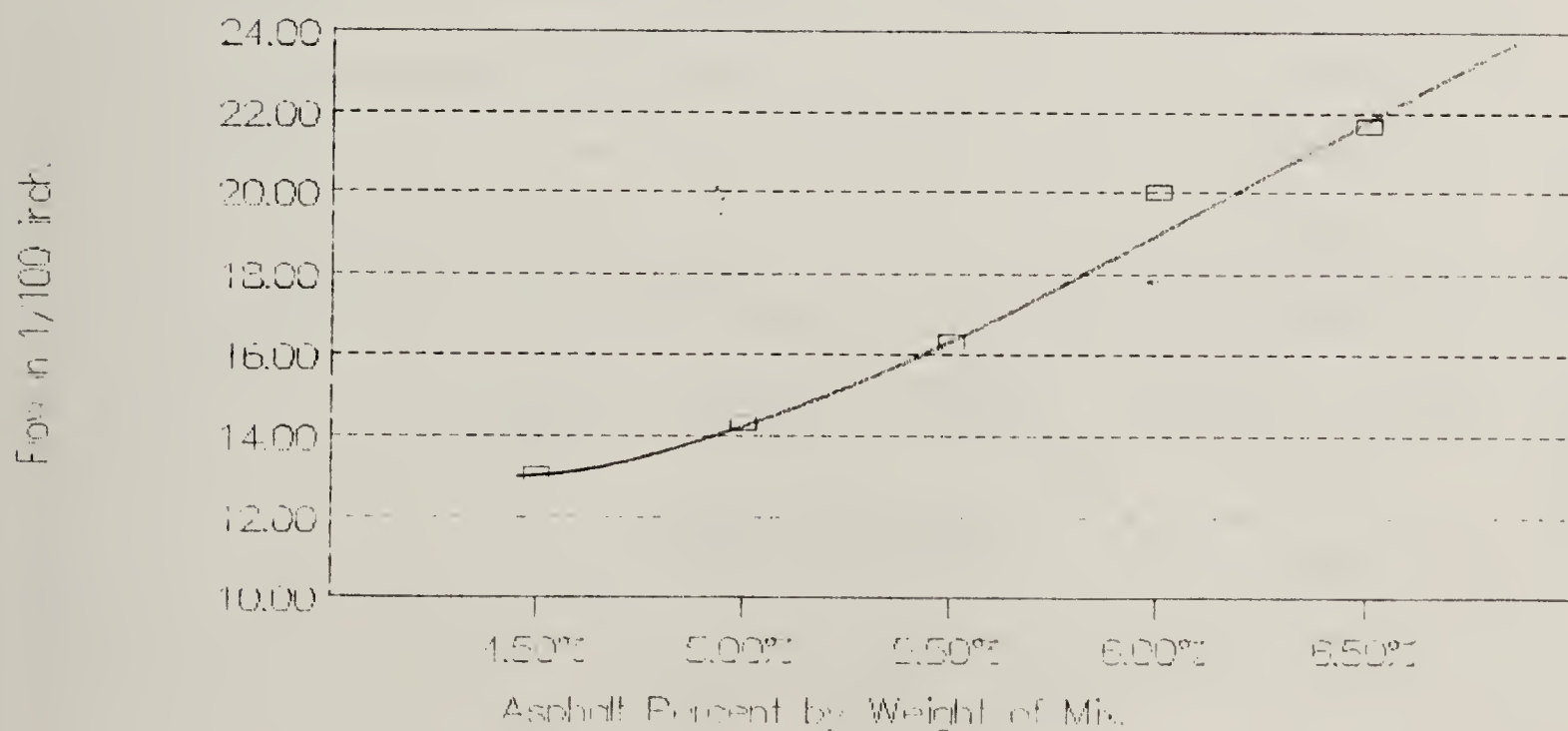
## Polybilt Mod. Conoco—Stability

I-Grad. without Selected Agg., 75-Blow.



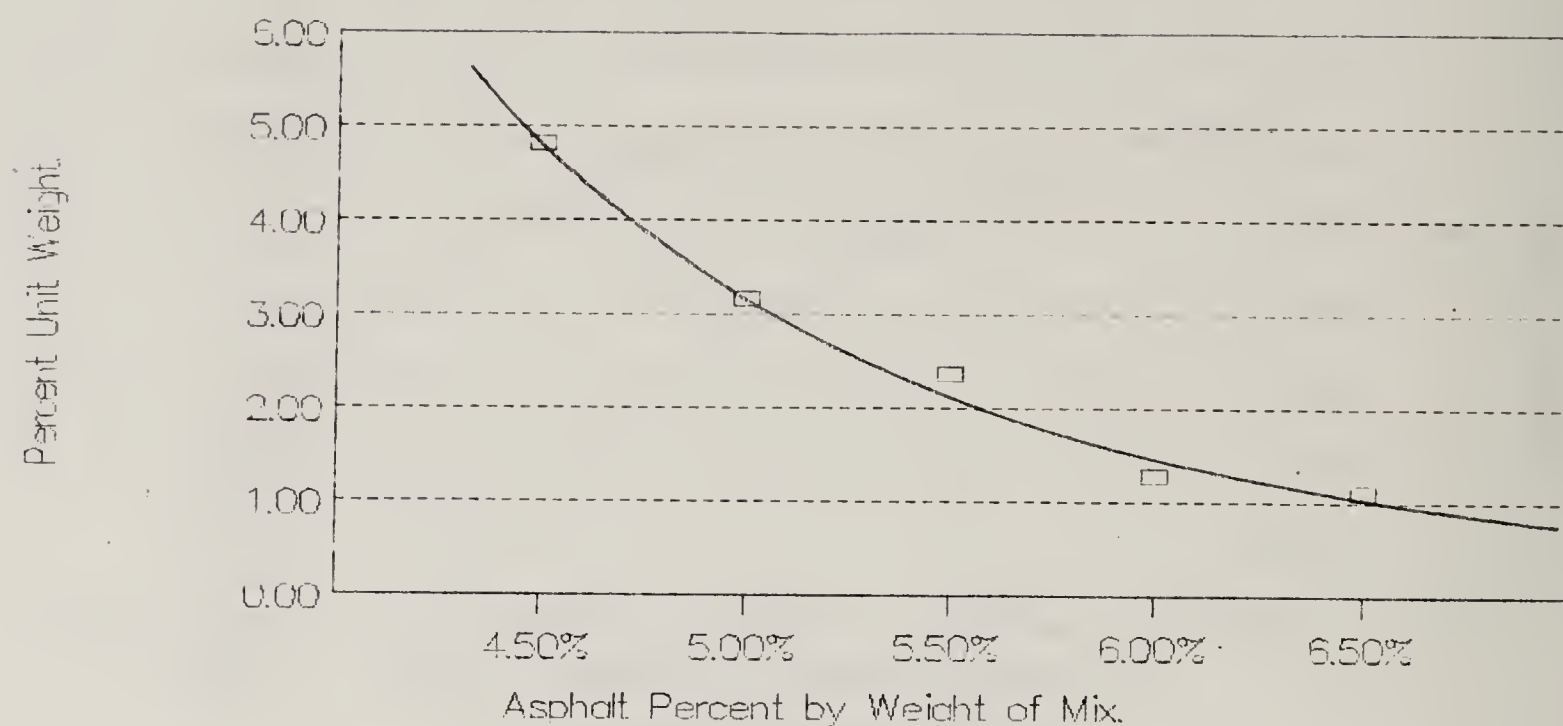
## Polybilt Mod. Conoco—Flow

I-Grad. without Selected Agg., 75-Blow.



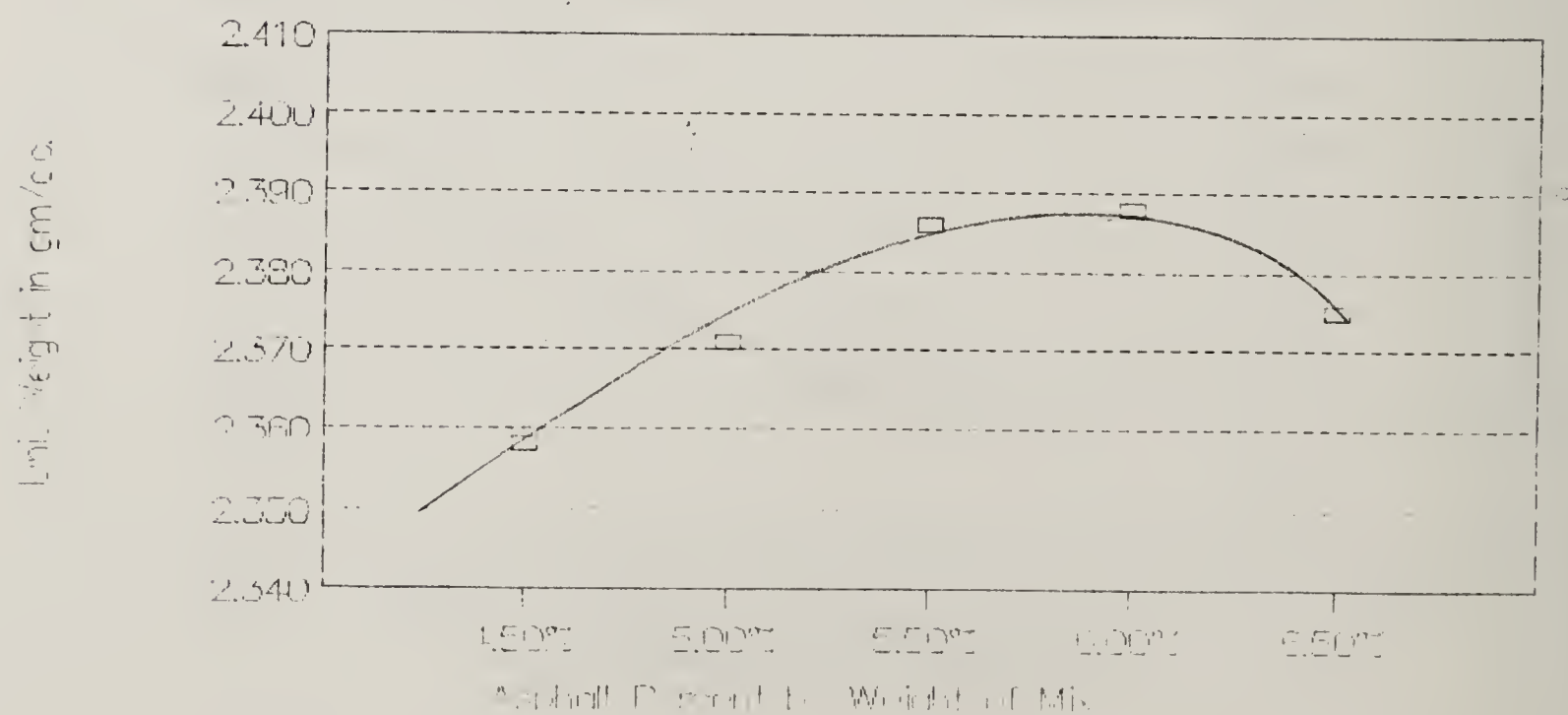
## Polybilt Mod. Conoco—Percent Air Voids.

I-Grad. without Selected Agg., 75-Blow.



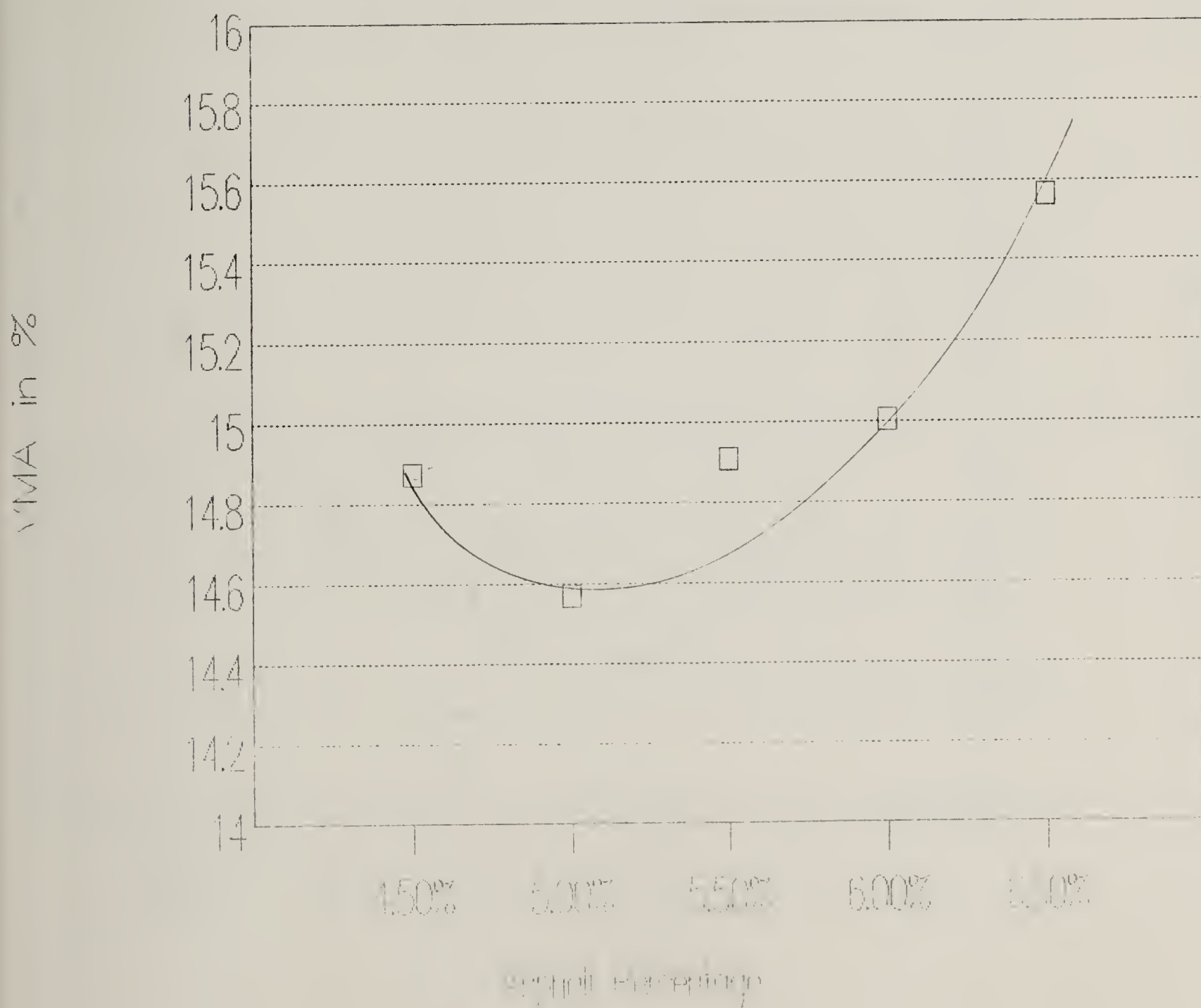
## Polybilt Mod. Conoco—Unit Weight.

I-Grad. without Selected Agg., 75-Blow.



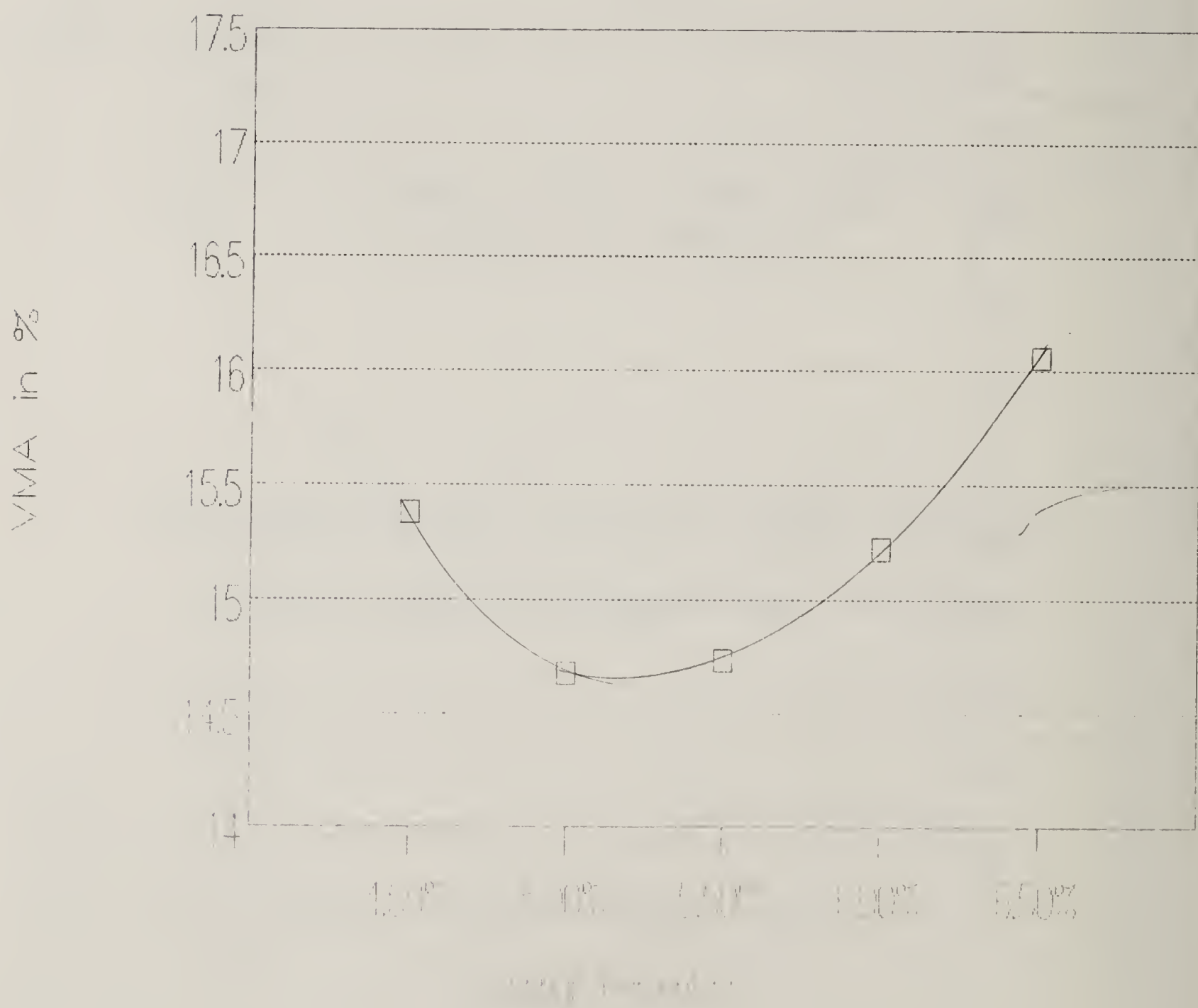
# Unmodified Cenex 120/150

VMA for 6 inch mold (75 Blows)



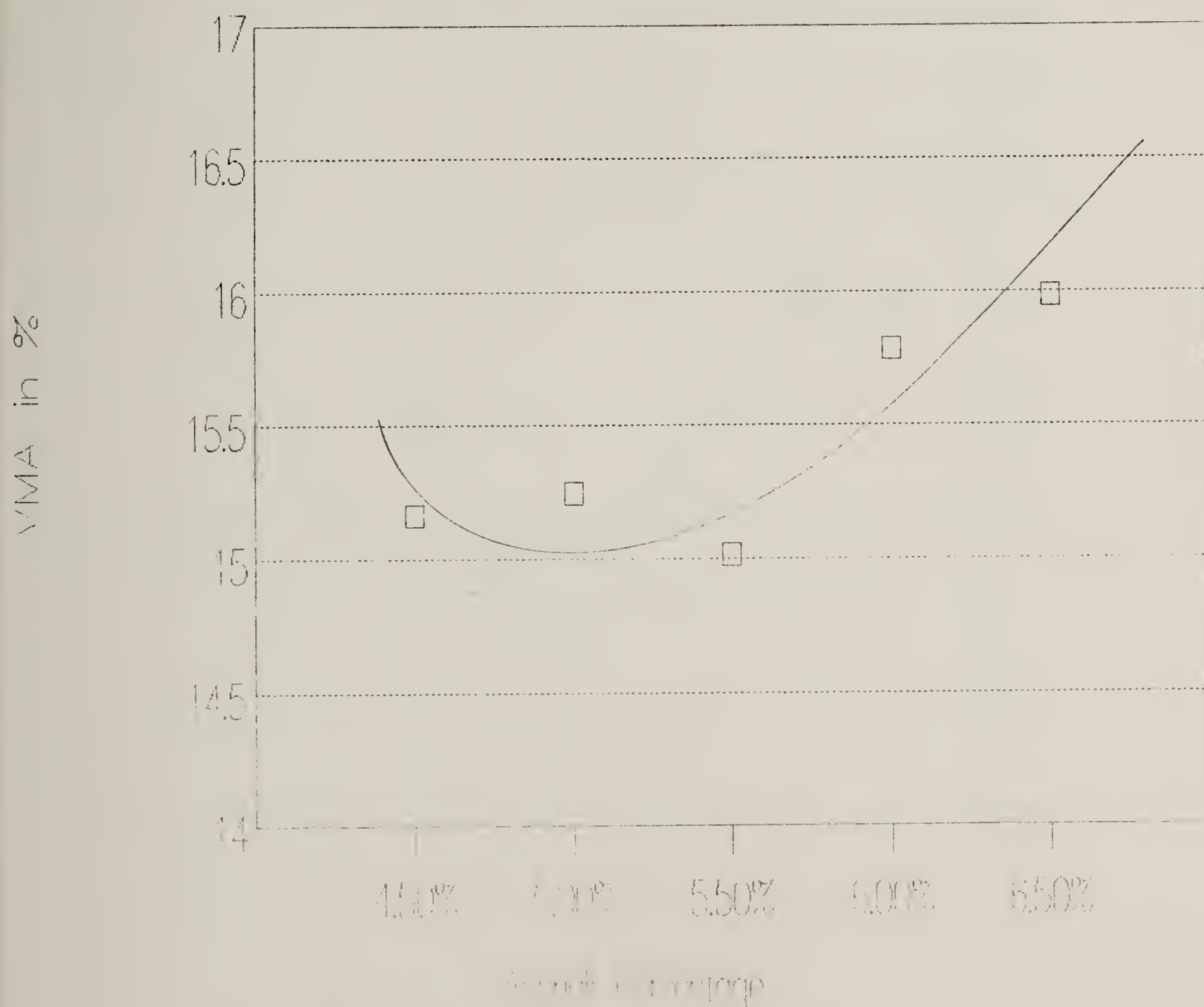
# Unmodified Conoco 120/150

VMA for 6 inch mold (75 Blows)



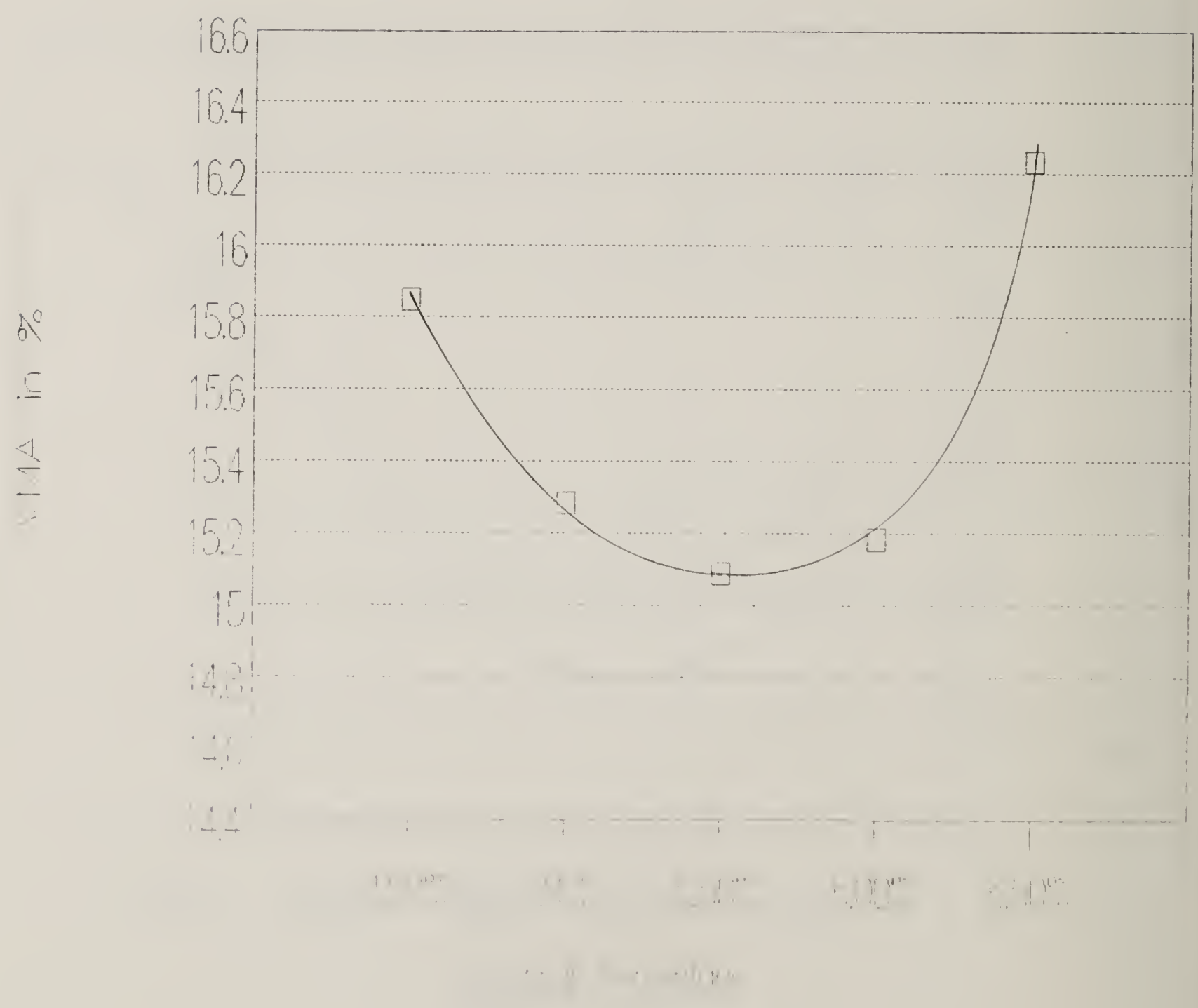
# Kraton Cenex 120/150

VMA for 6 inch mold (75 Blows)



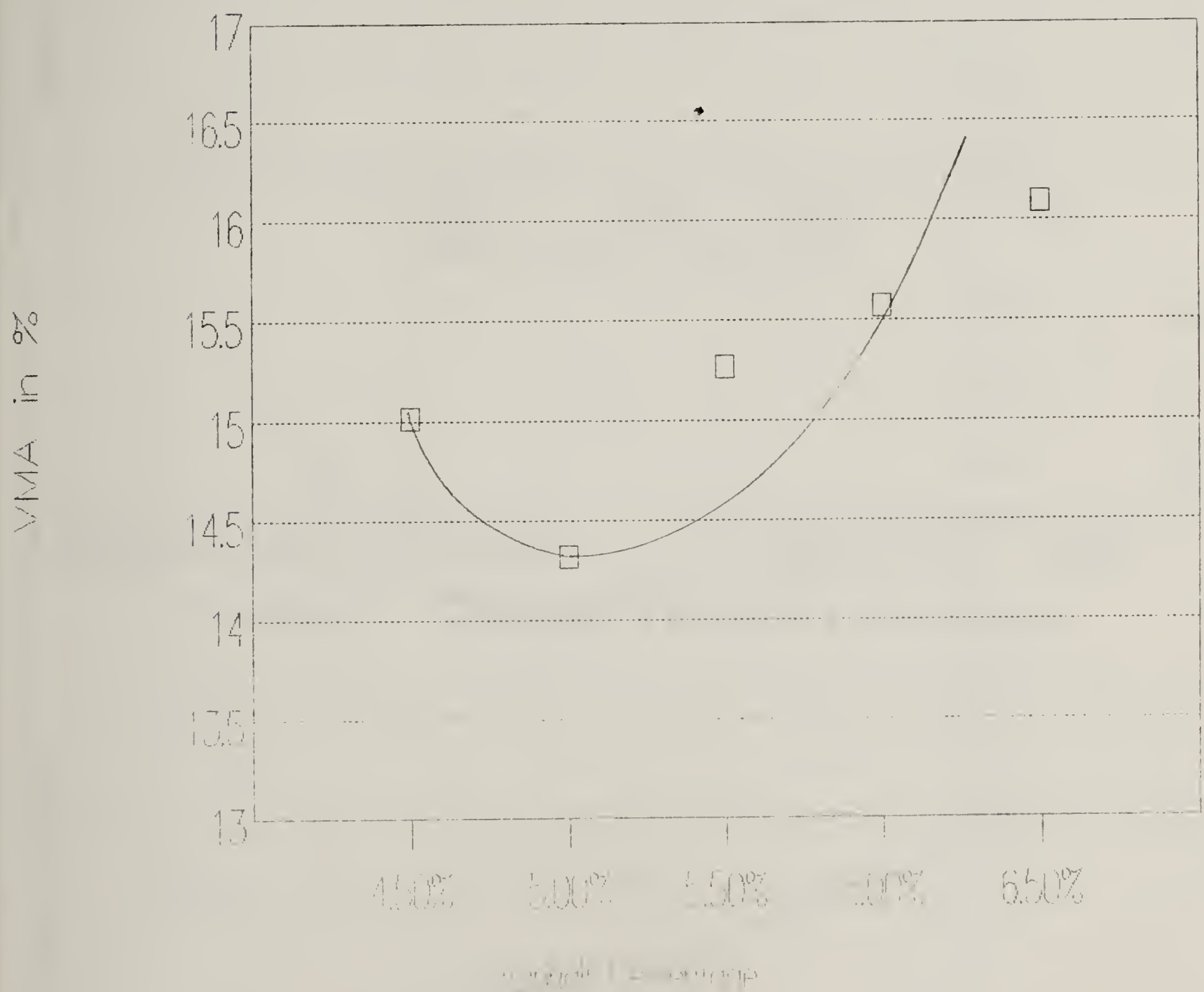
# Kraton Conoco 120/150

VMA for 6 inch mold (75 Blows)



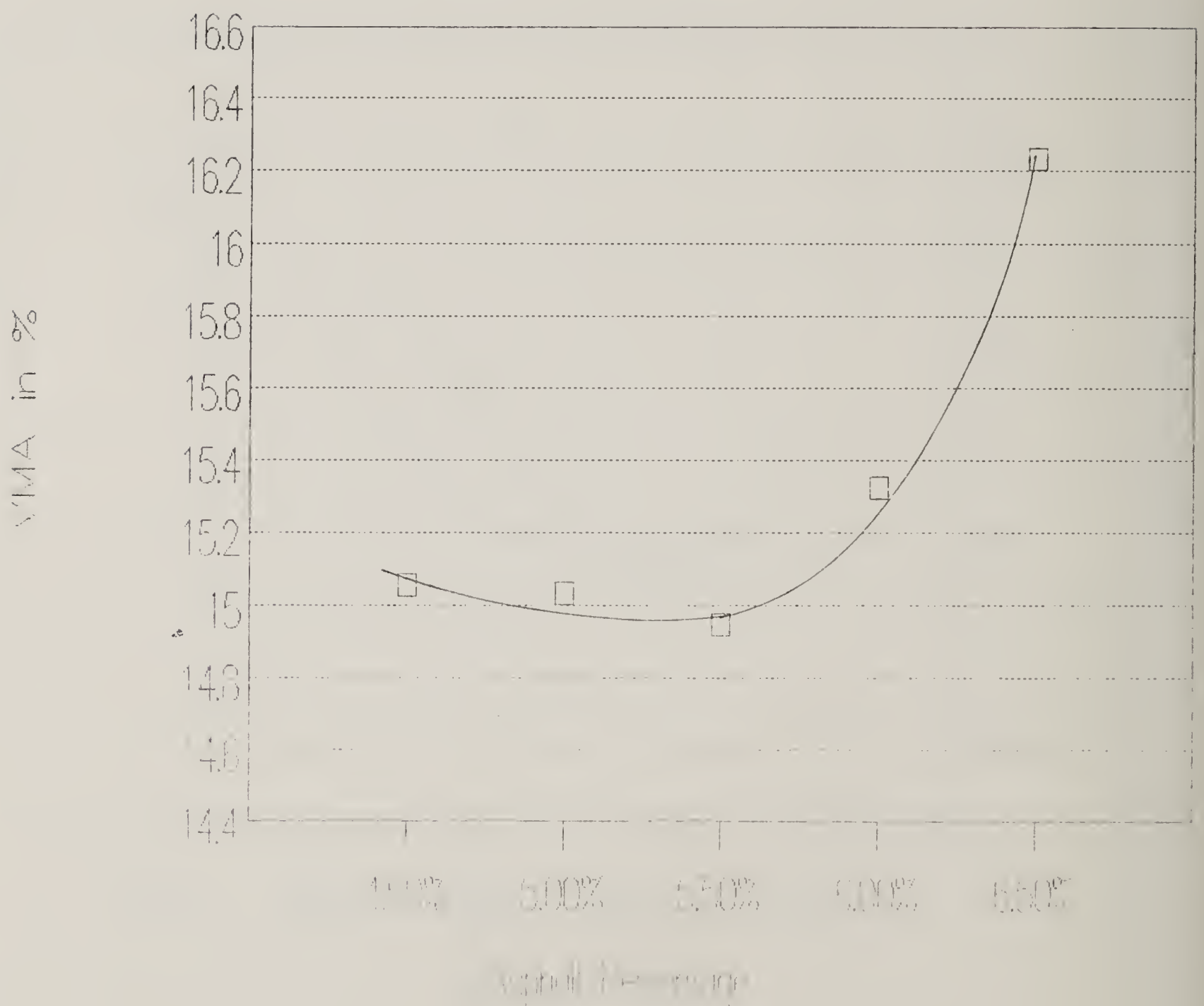
# Polybilt Cenex 120/150

VMA for 6 inch mold (75 Blows)



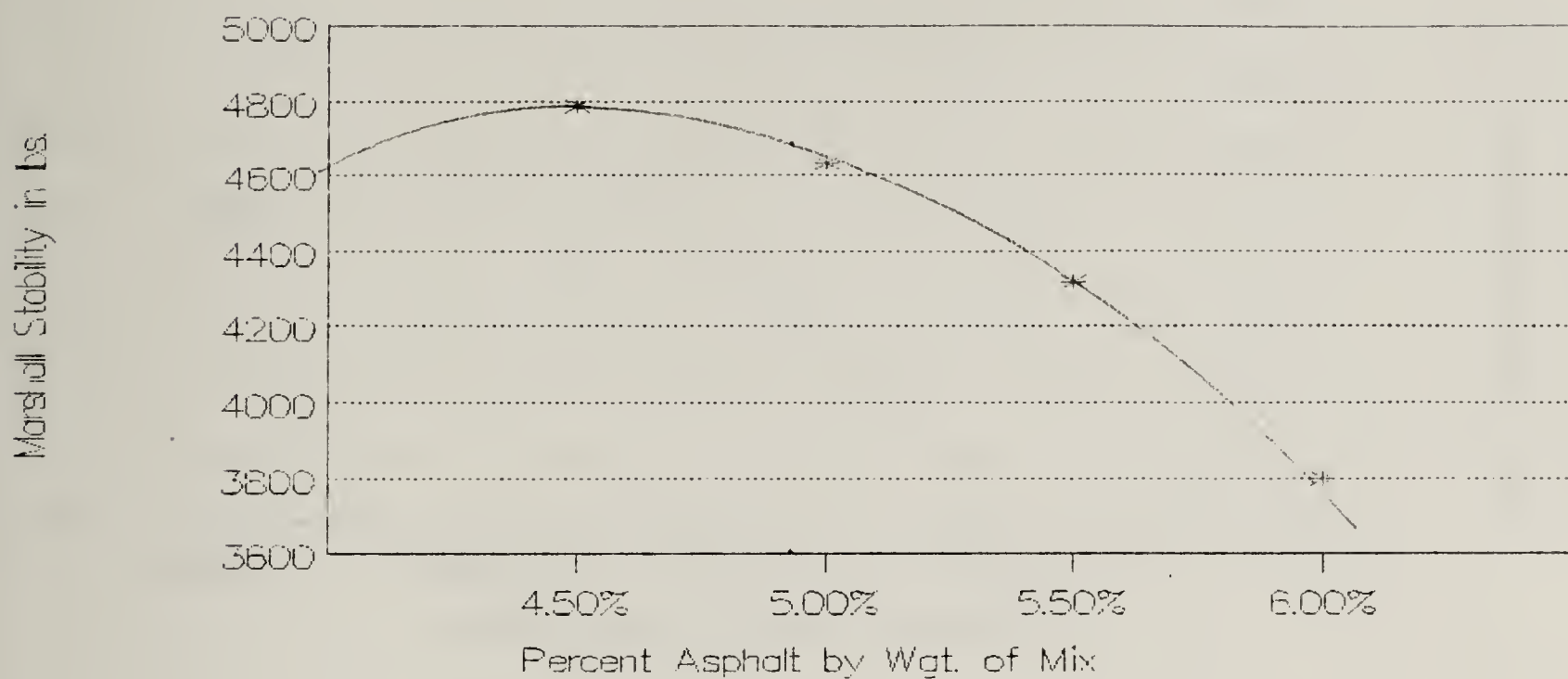
# Polybilt Conoco 120/150

VMA for 6 inch mold (75 Blows)



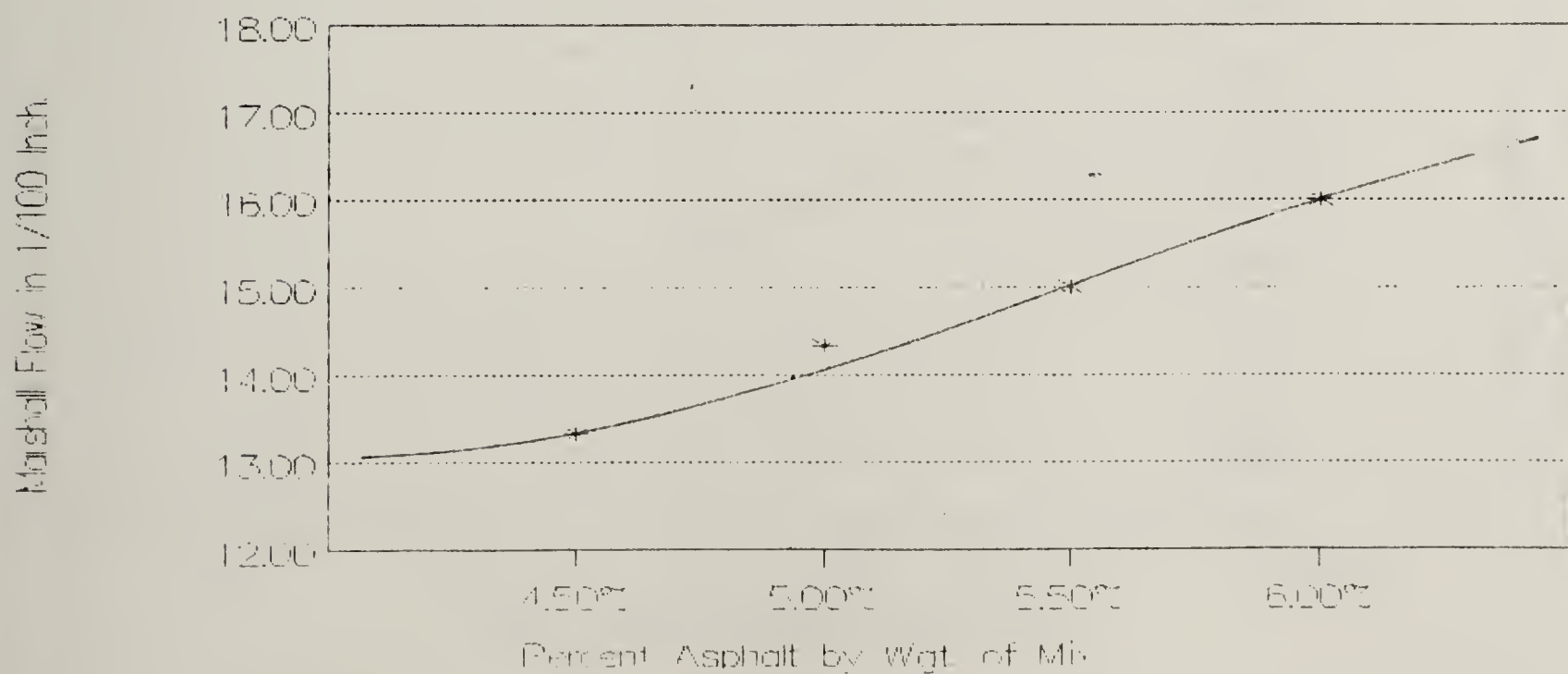
## Unmodified Cenex - I Gradation Agg.

75 Blow - Marshall Stability in lbs.



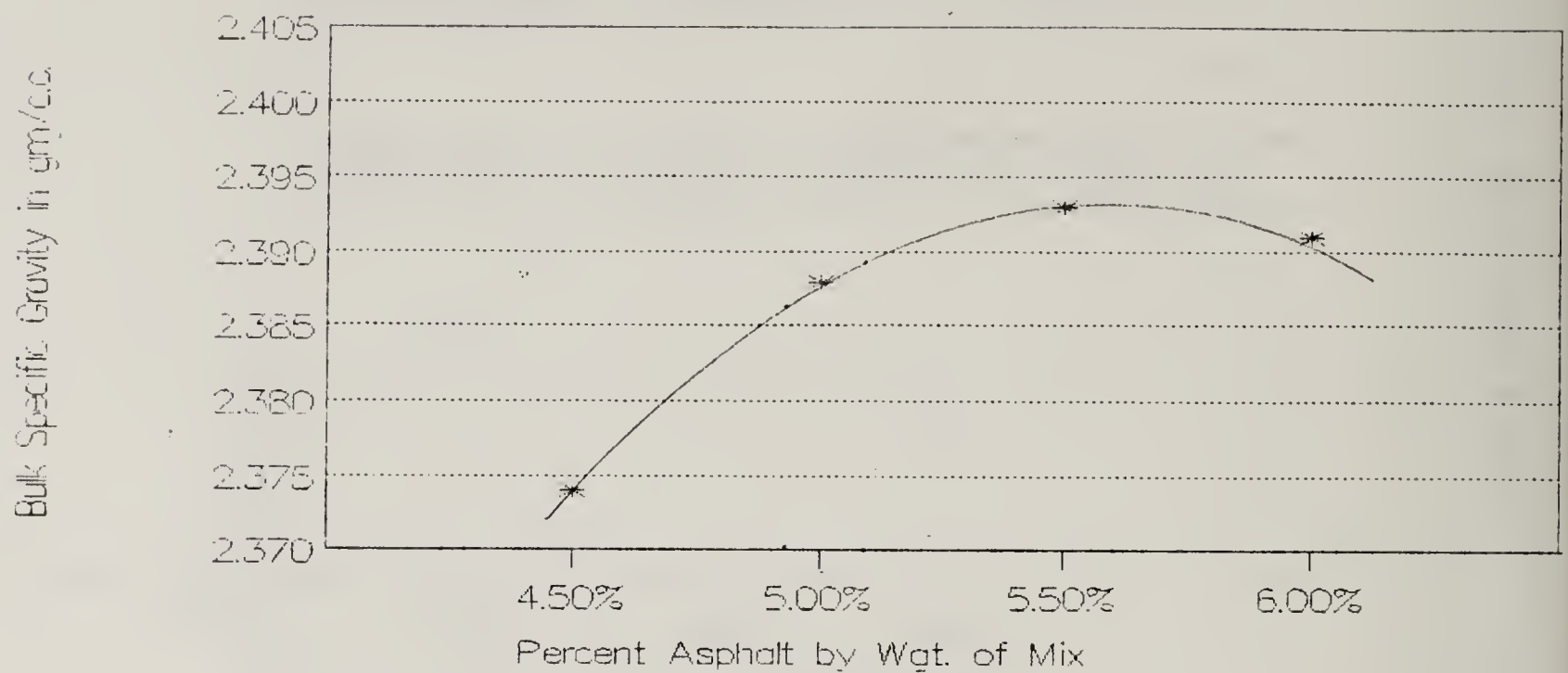
## Unmodified Cenex - I Gradation Agg.

75 Blow - Marshall Flow in 1/100 Inch.



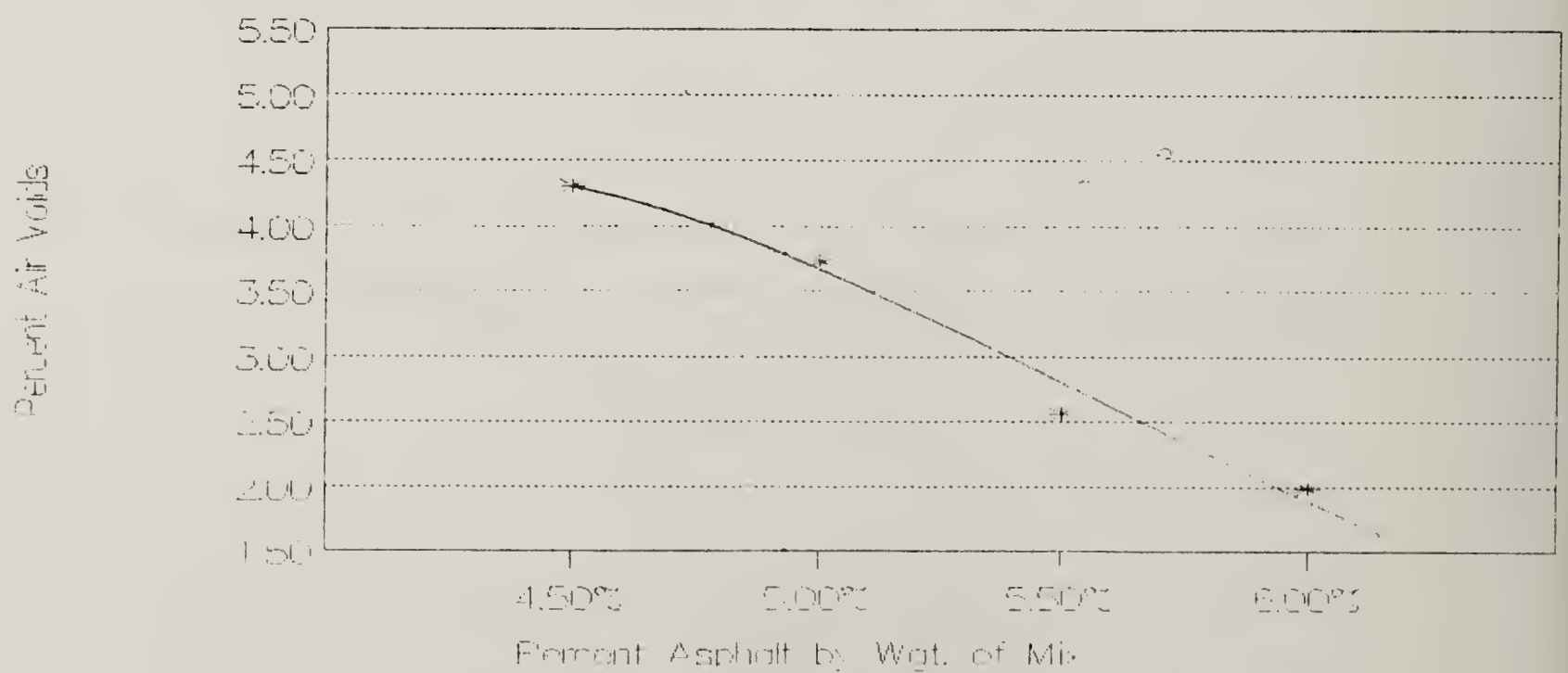
# Unmodified Cenex - I Gradation Agg.

75 Blow - Bulk Specific Gravity.



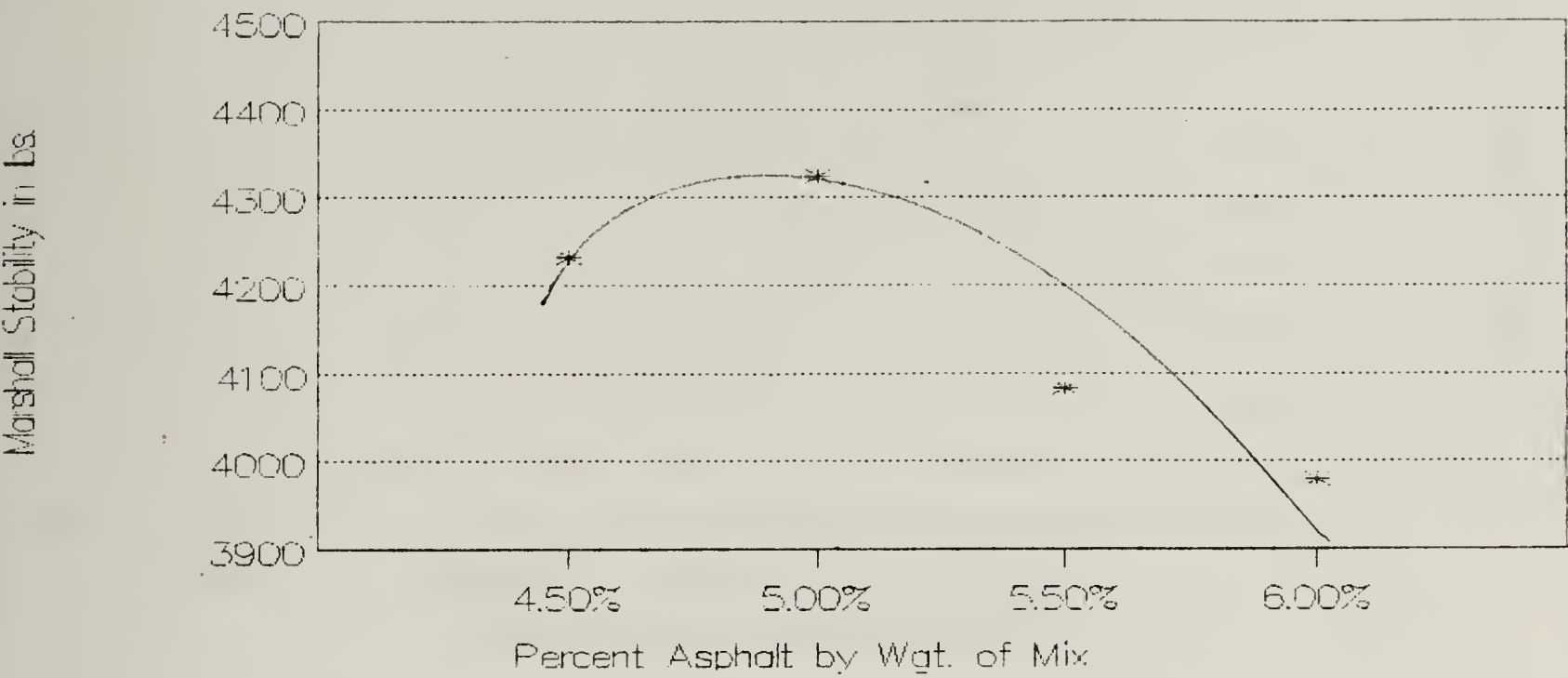
# Unmodified Cenex - I Gradation Agg.

75 Blow - Percent Air Voids



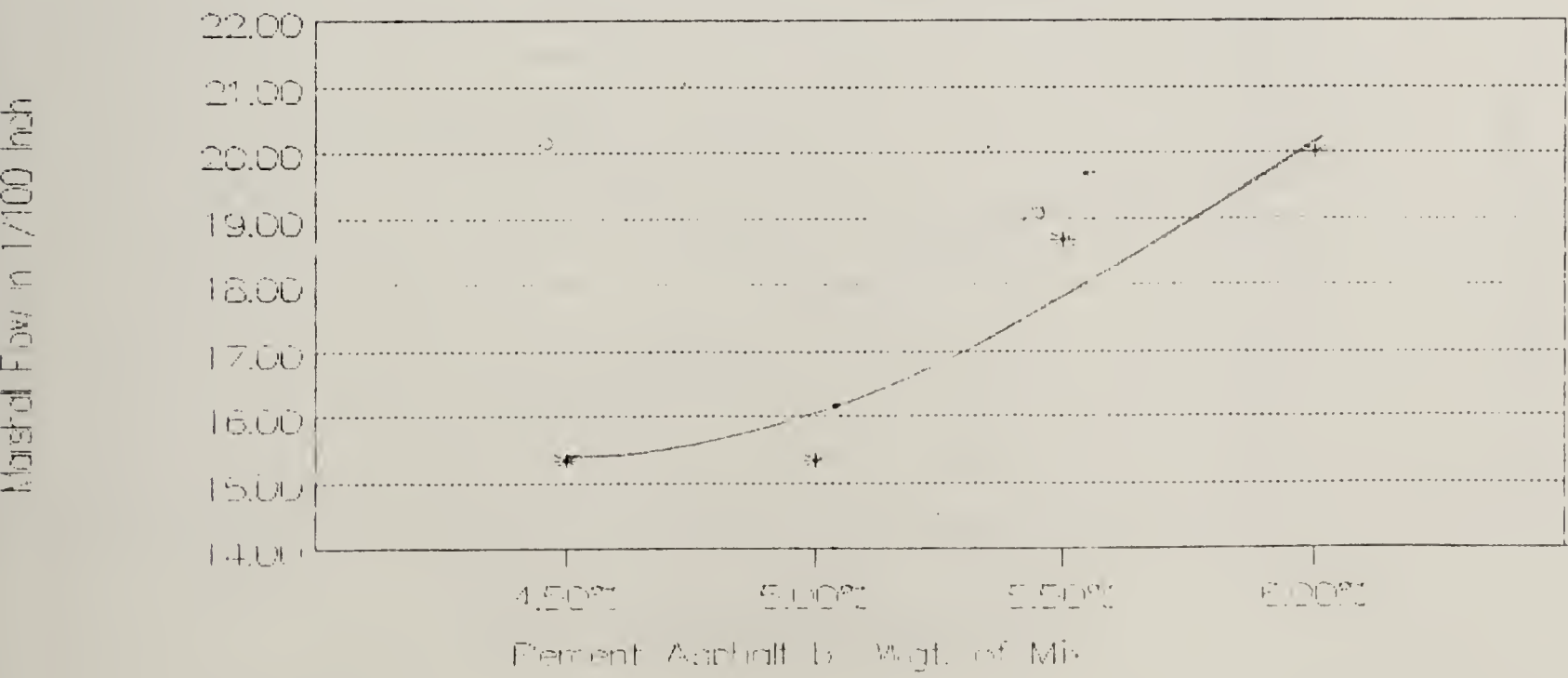
Kraton Mod. Cenex — I Gradation Agg.

75 Blow — Marshall Stability in lbs.



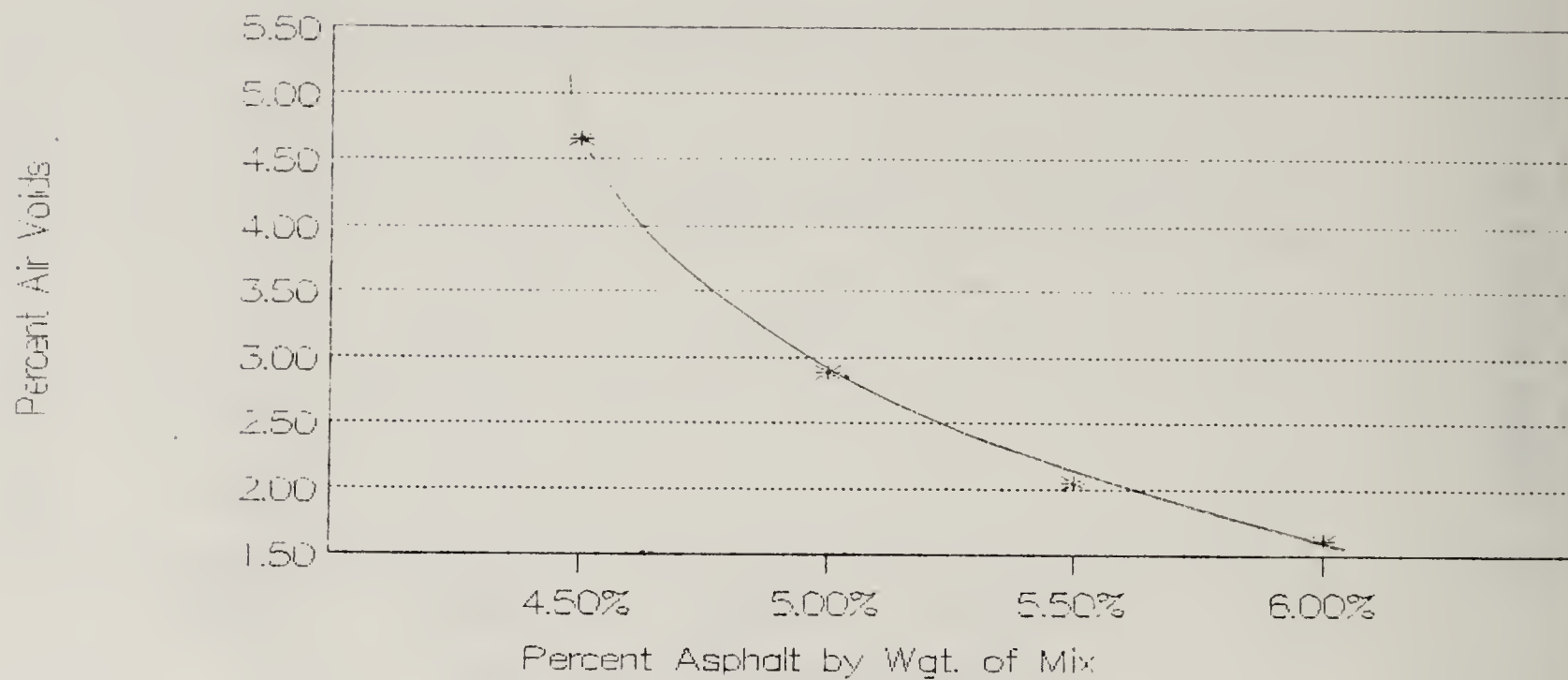
Kraton Mod. Cenex — I Gradation Agg.

75 Blow — Marshall Flow in 1/100 Inch.



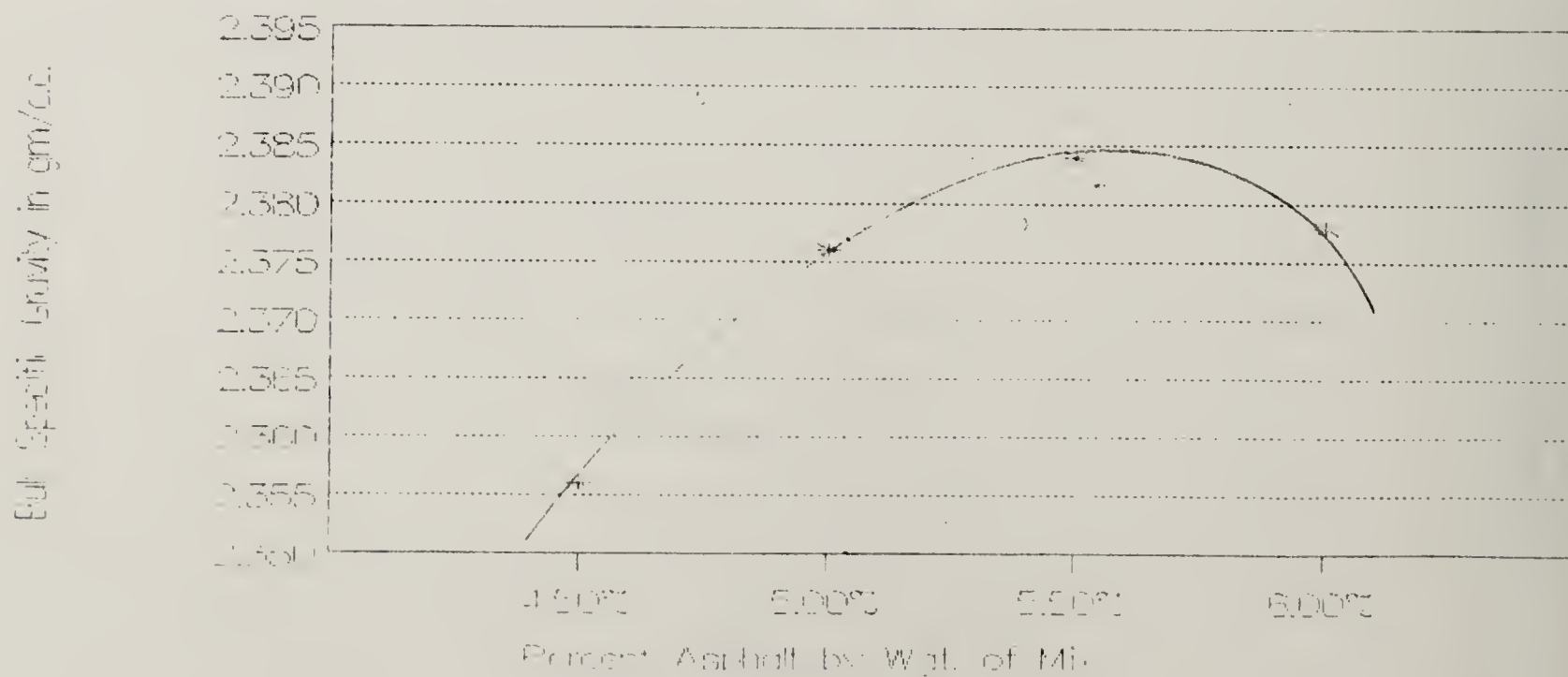
# Kraton Mod. Cenex - I Gradation Agg.

## 75 Blow - Percent Air Voids



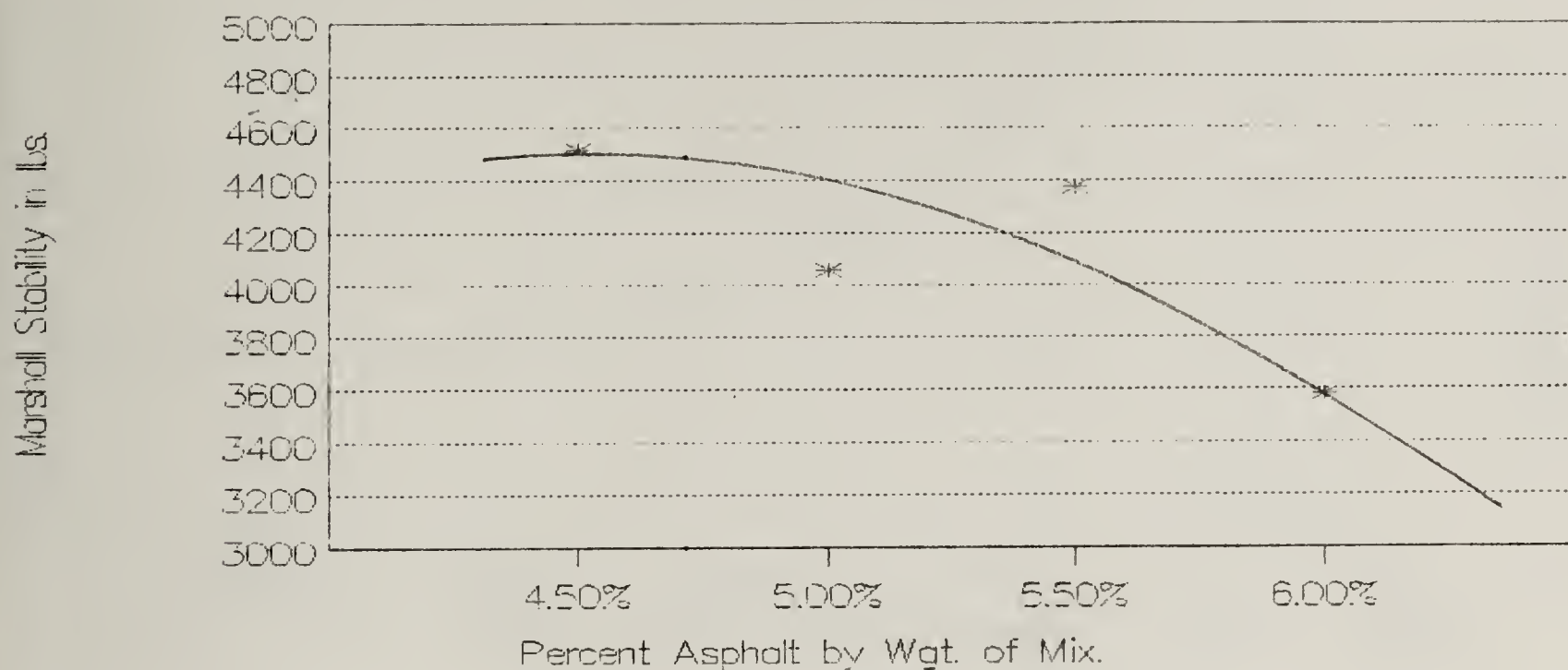
# Kraton Mod. Cenex - I Gradation Agg.

## 75 Blow - Bulk Specific Gravity



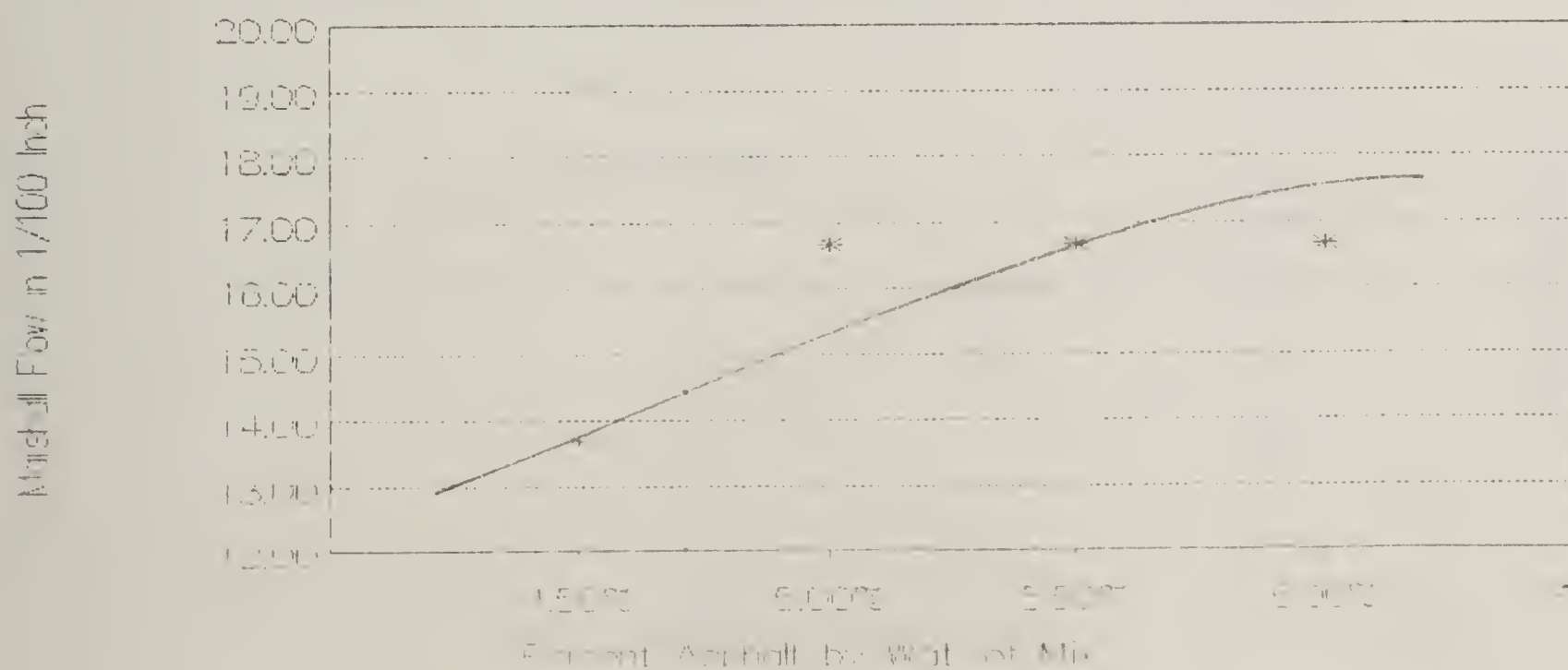
# Polybilt Mod. Cenex - I Gradation Agg.

## 75 Blow - Marshall Stability.



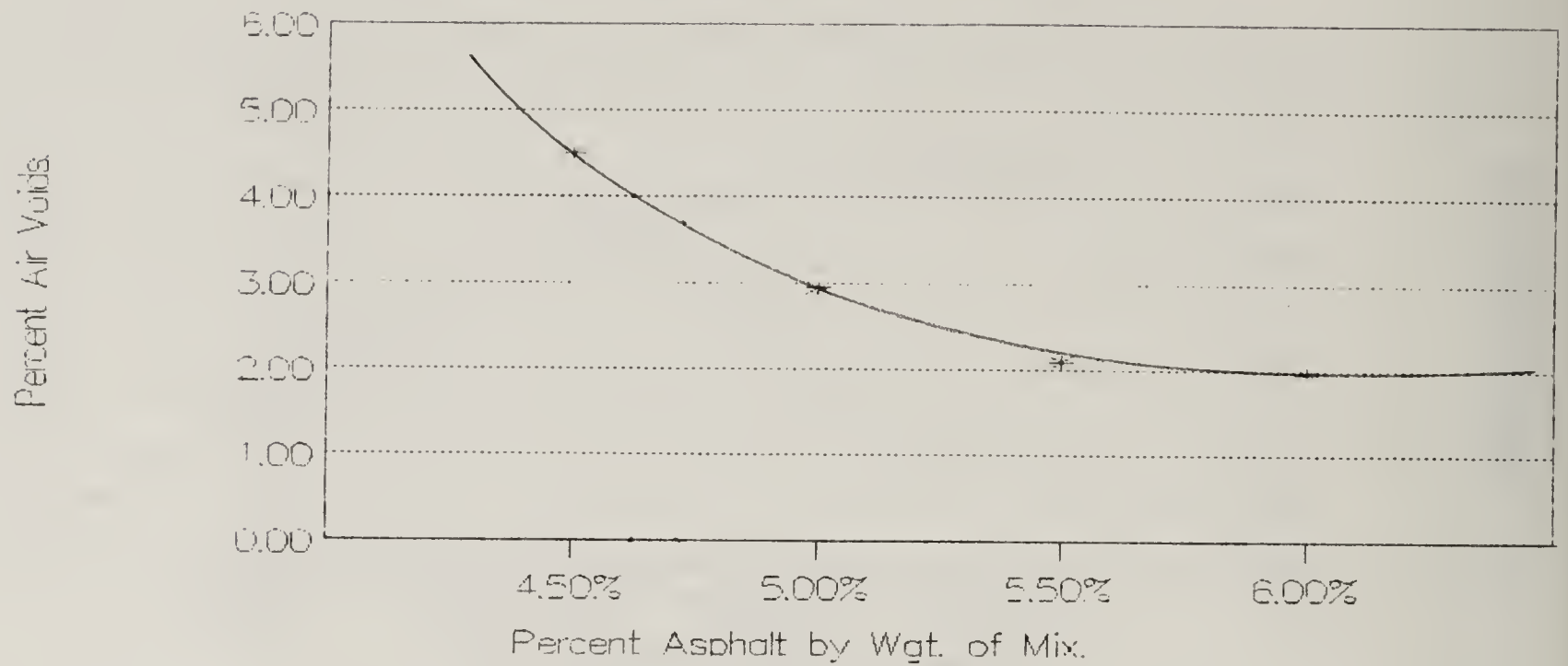
# Polybilt Mod. Cenex - I Gradation Agg.

## 75 Blow - Marshall Flow.



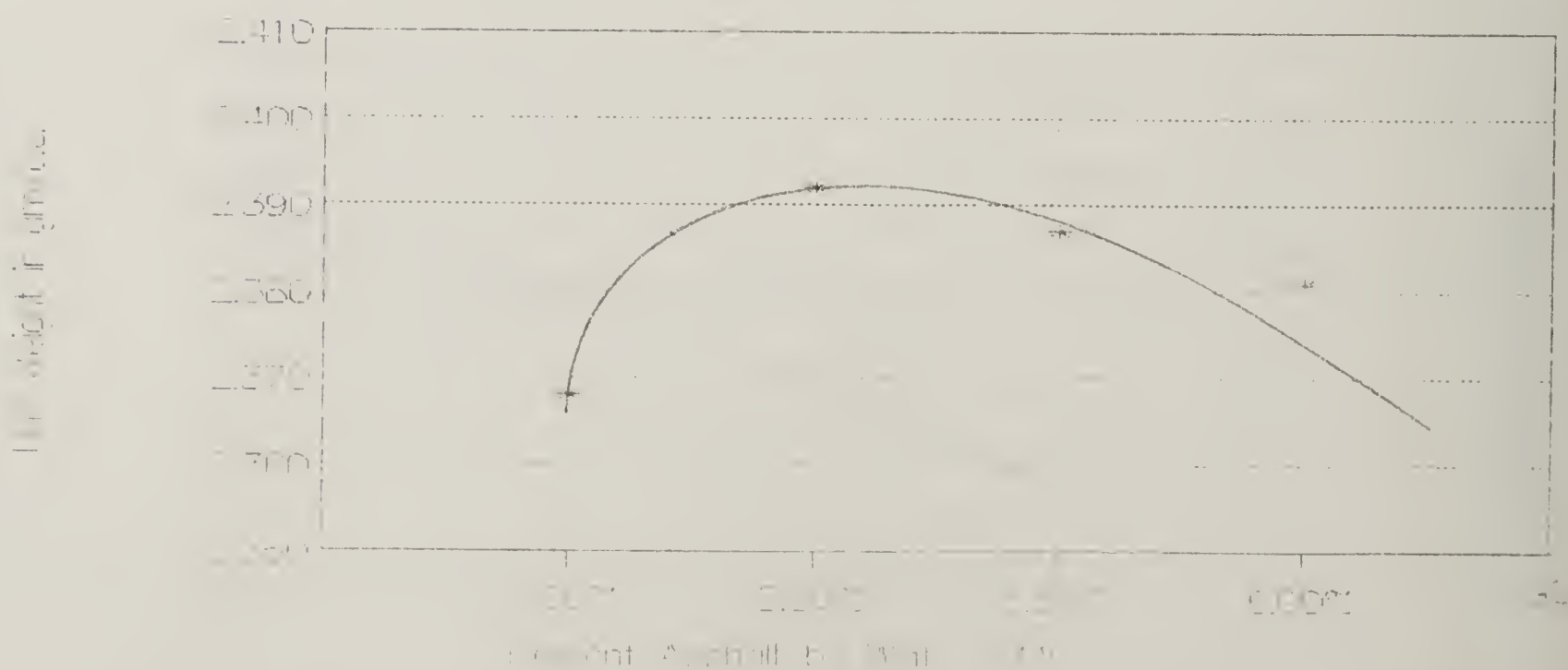
# Polybilt Mod. Cenex - I Gradation Agg.

75 Blow - Percent Air Voids.



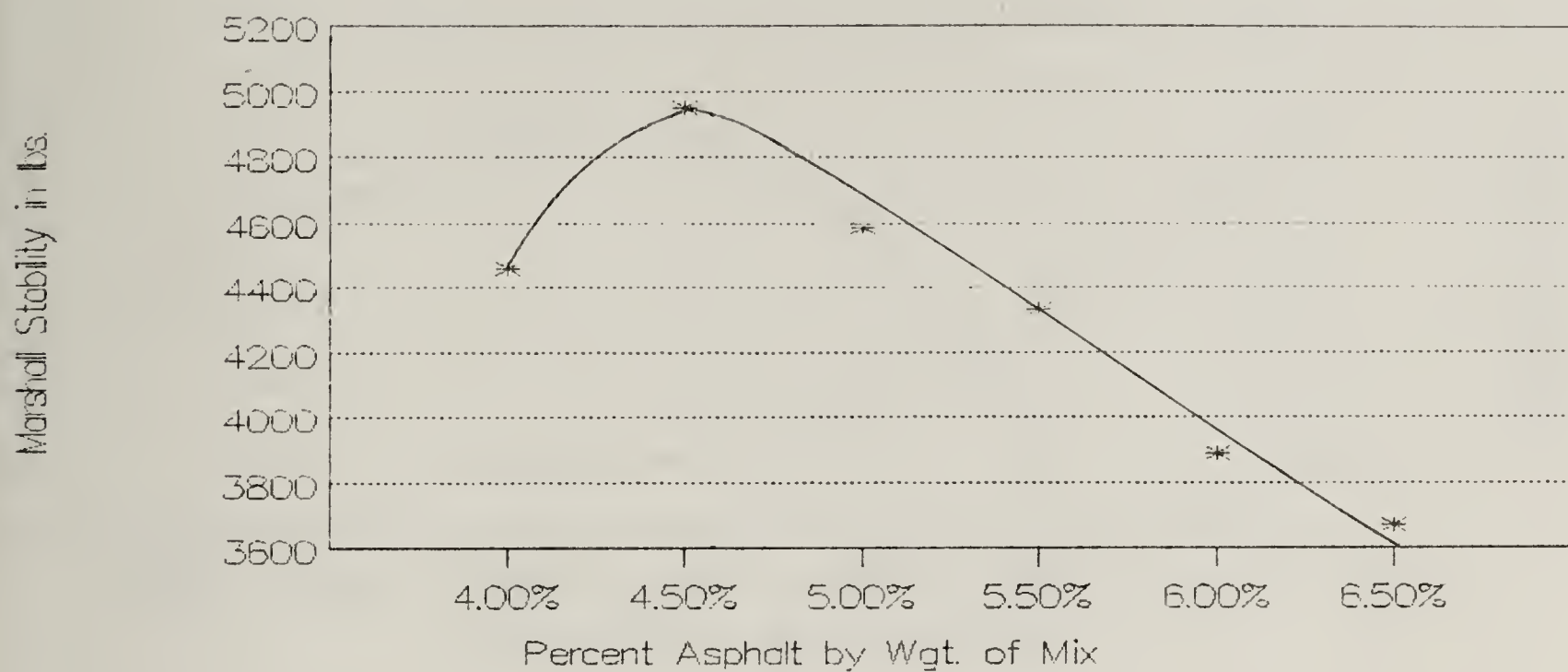
# Polybilt Mod. Cenex - I Gradation Agg.

75 Blow - Unit Weight in gm/c.c.



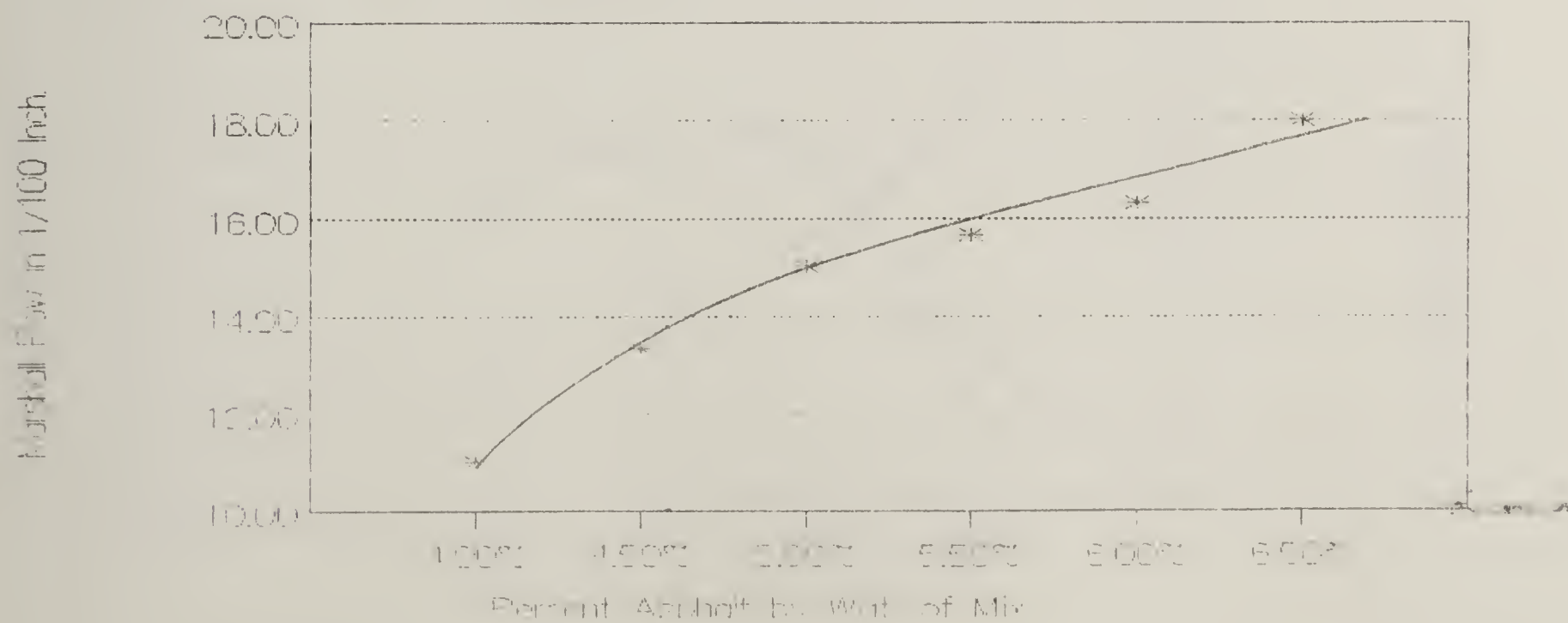
# Unmodified Cenex - I Gradation Agg.

112 Blow - Marshall Stability in lbs.



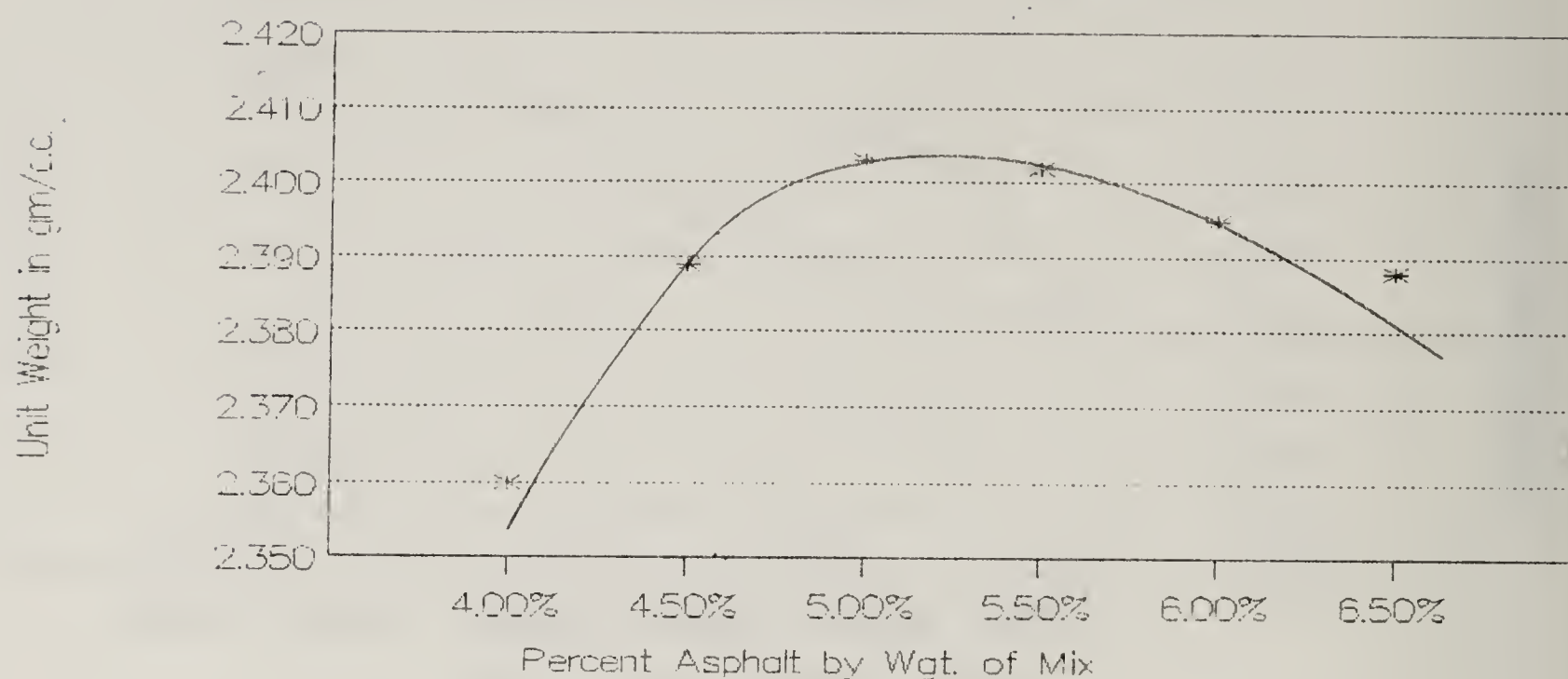
# Unmodified Cenex - I Gradation Agg.

112 Blow - Marshall Flow in 1/100 Inch.



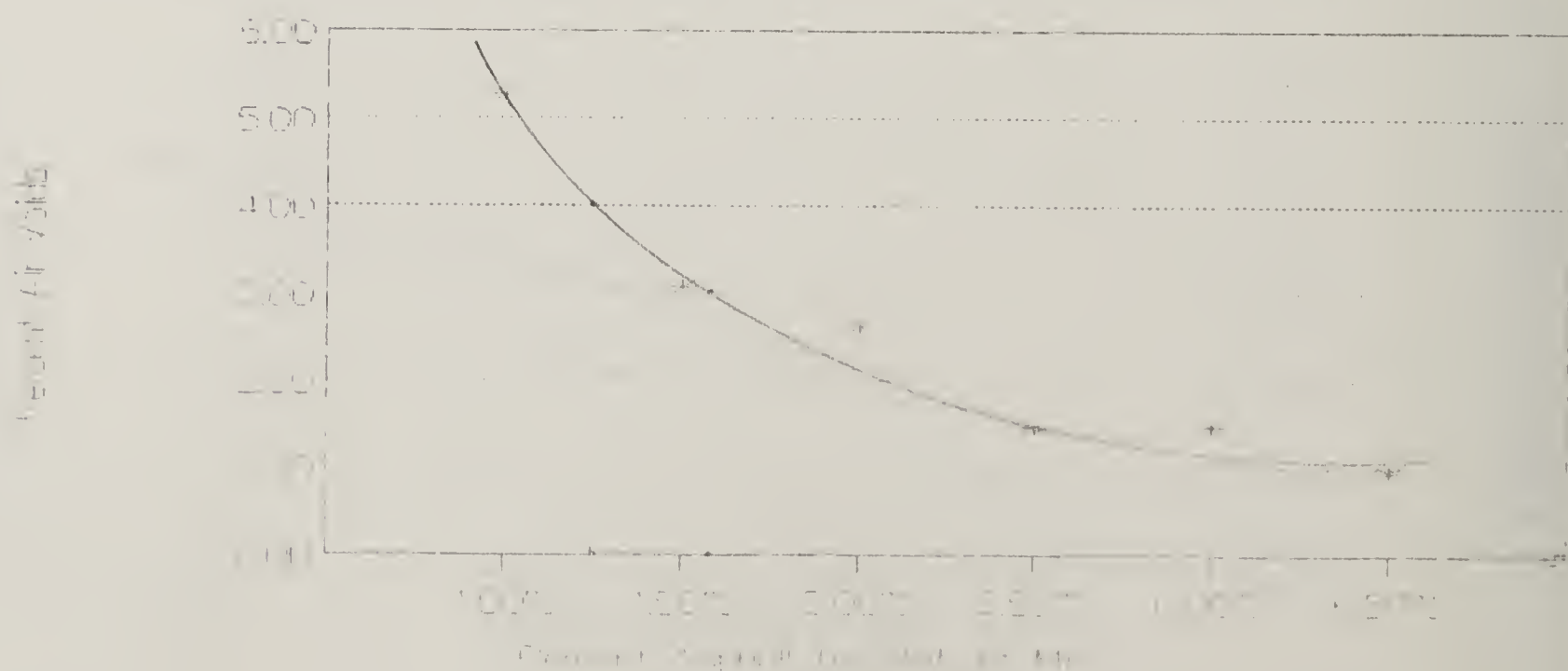
# Unmodified Cenex - I Gradation Agg.

112 Blow - Unit Weight in gm/c.c.



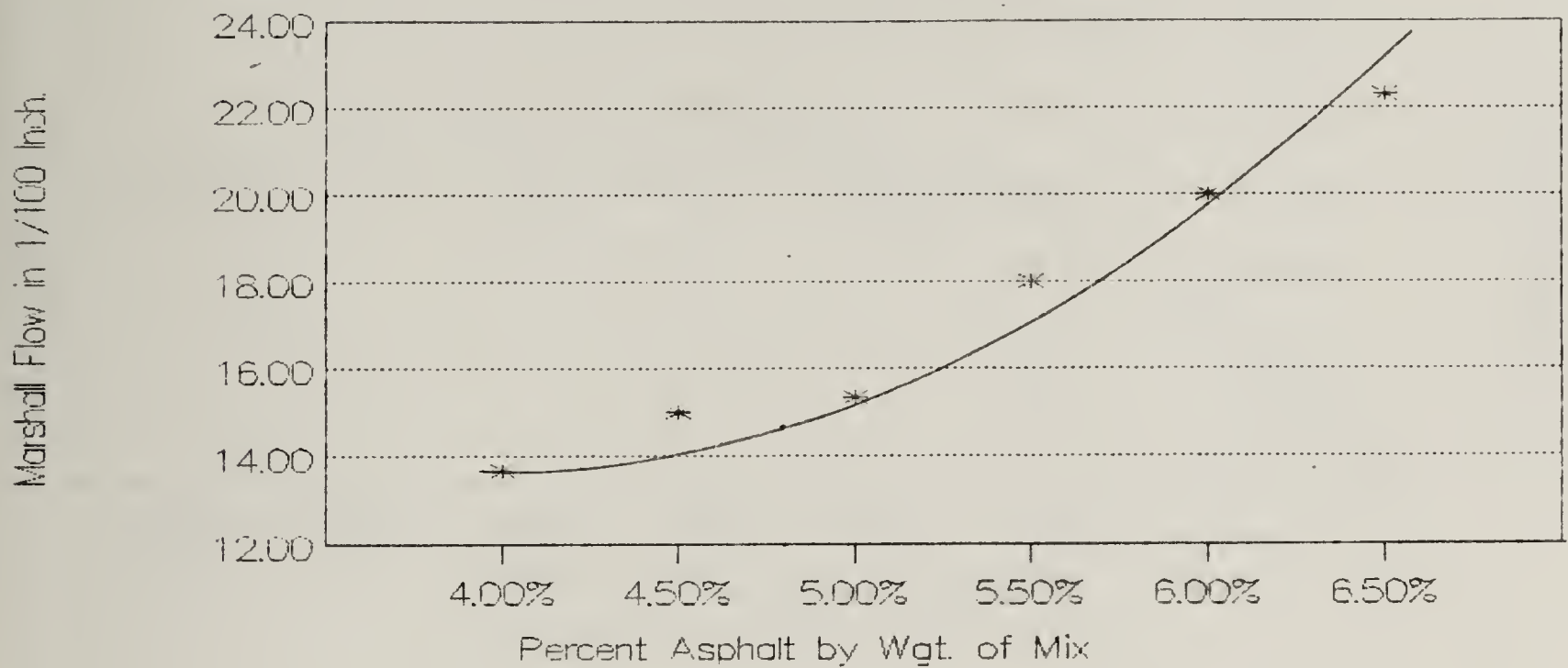
# Unmodified Cenex - I Gradation Agg.

112 Blow - Percent Air Voids.



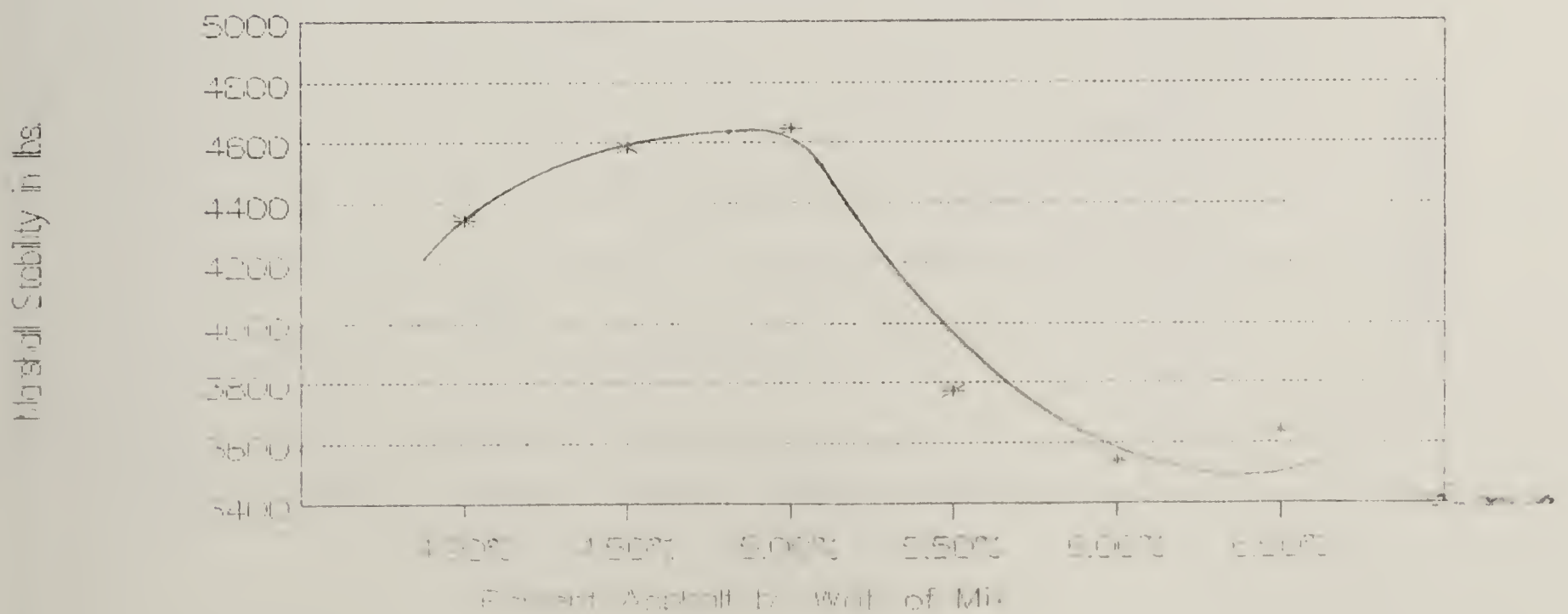
## Kraton Mod. Cenex - I Gradation Agg.

112 Blow - Marshall Flow in 1/100 Inch.



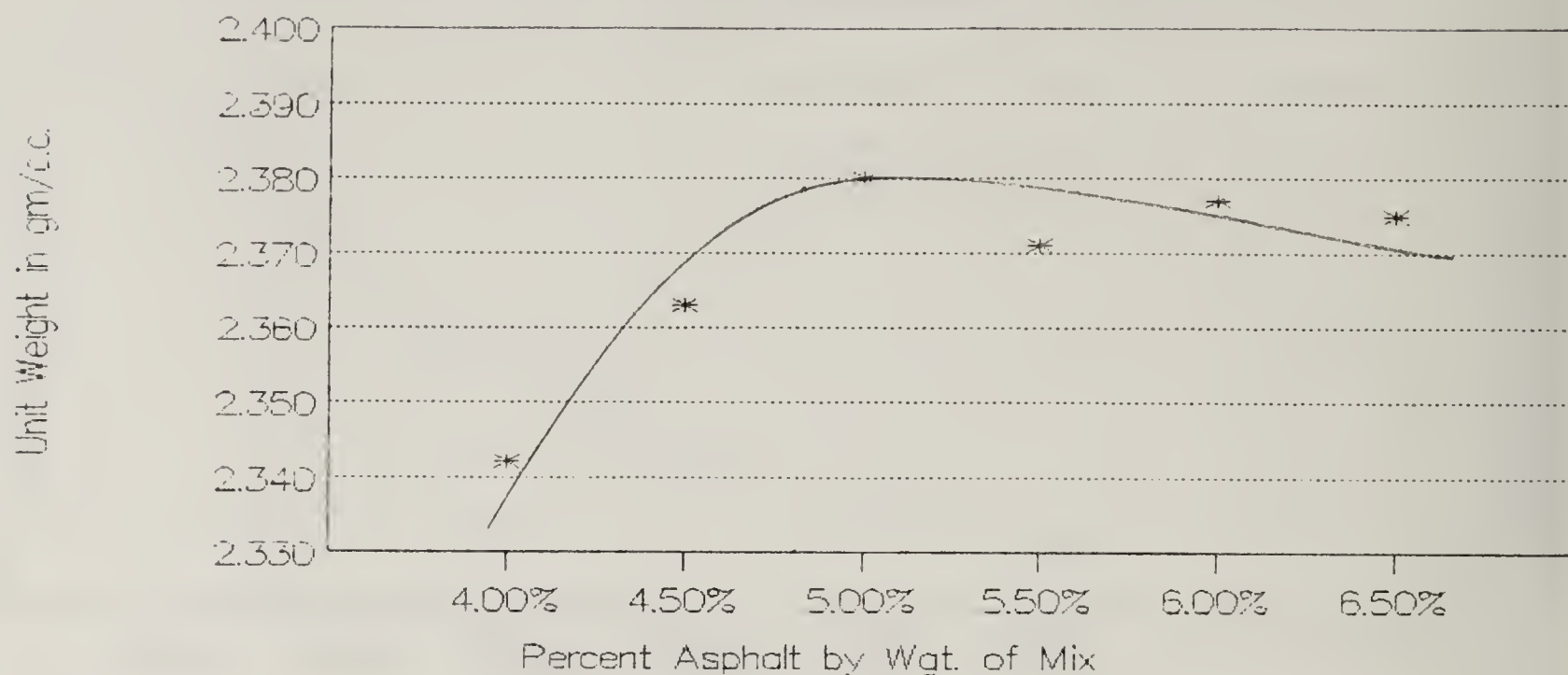
## Kraton Mod. Cenex - I Gradation Agg.

112 Blow - Marshall Stability in lbs.



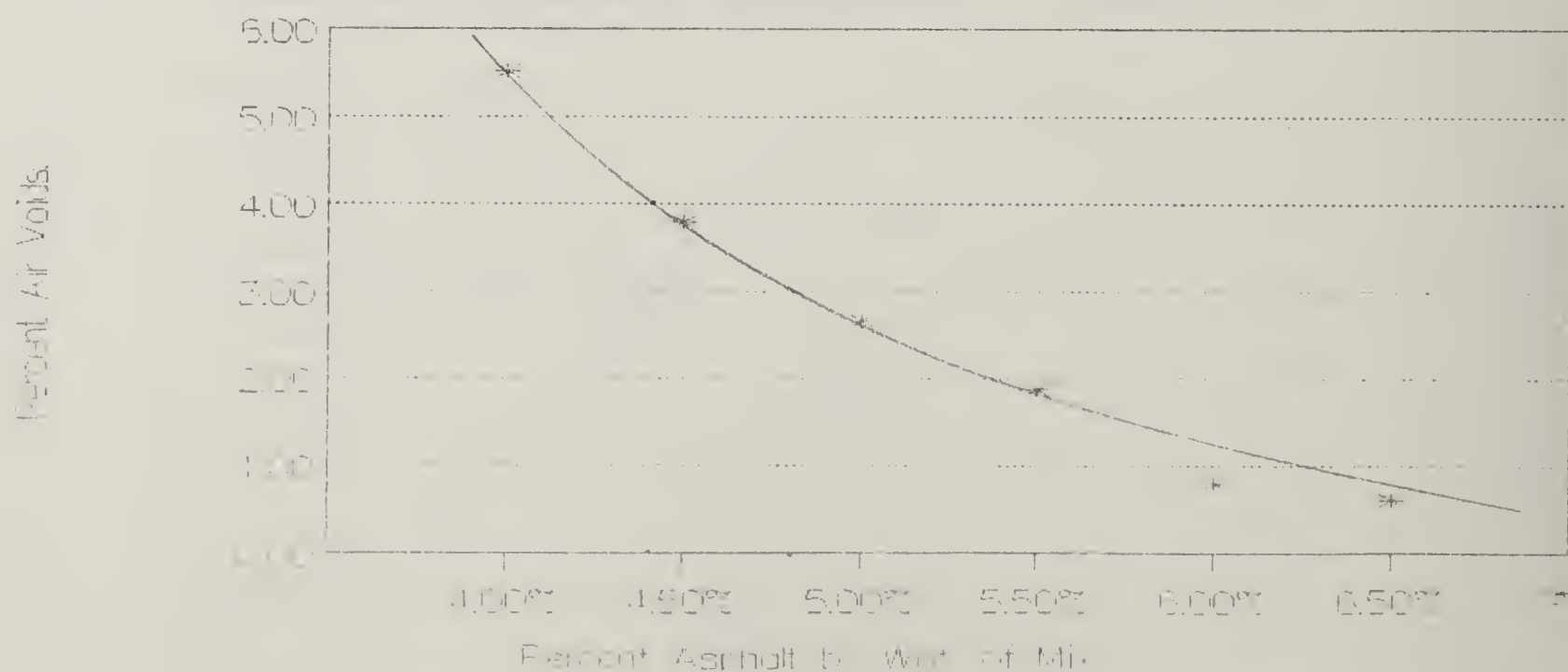
# Kraton Mod. Cenex — I Gradation Agg.

112 Blow — Unit Weight in gm/c.c.



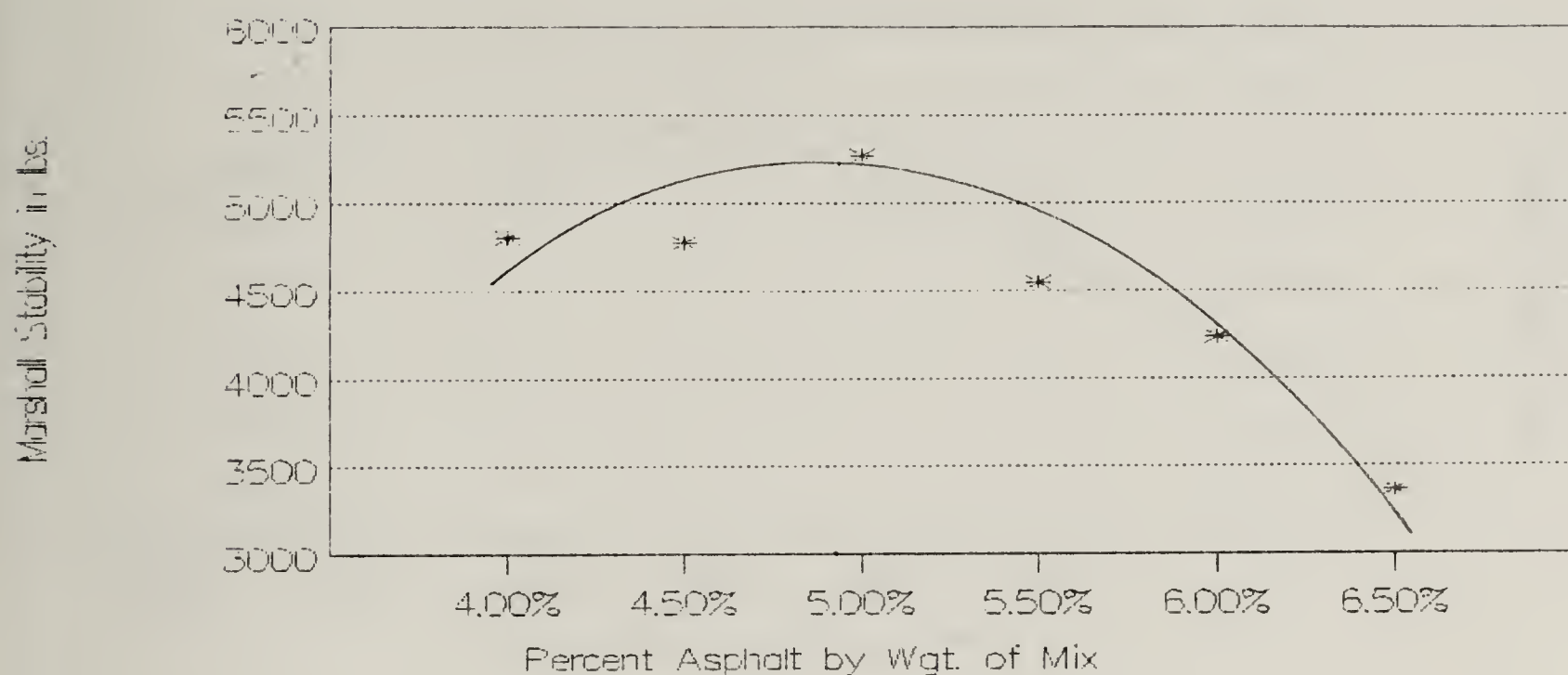
# Kraton Mod. Cenex — I Gradation Agg.

112 Blow — Percent Air Voids.



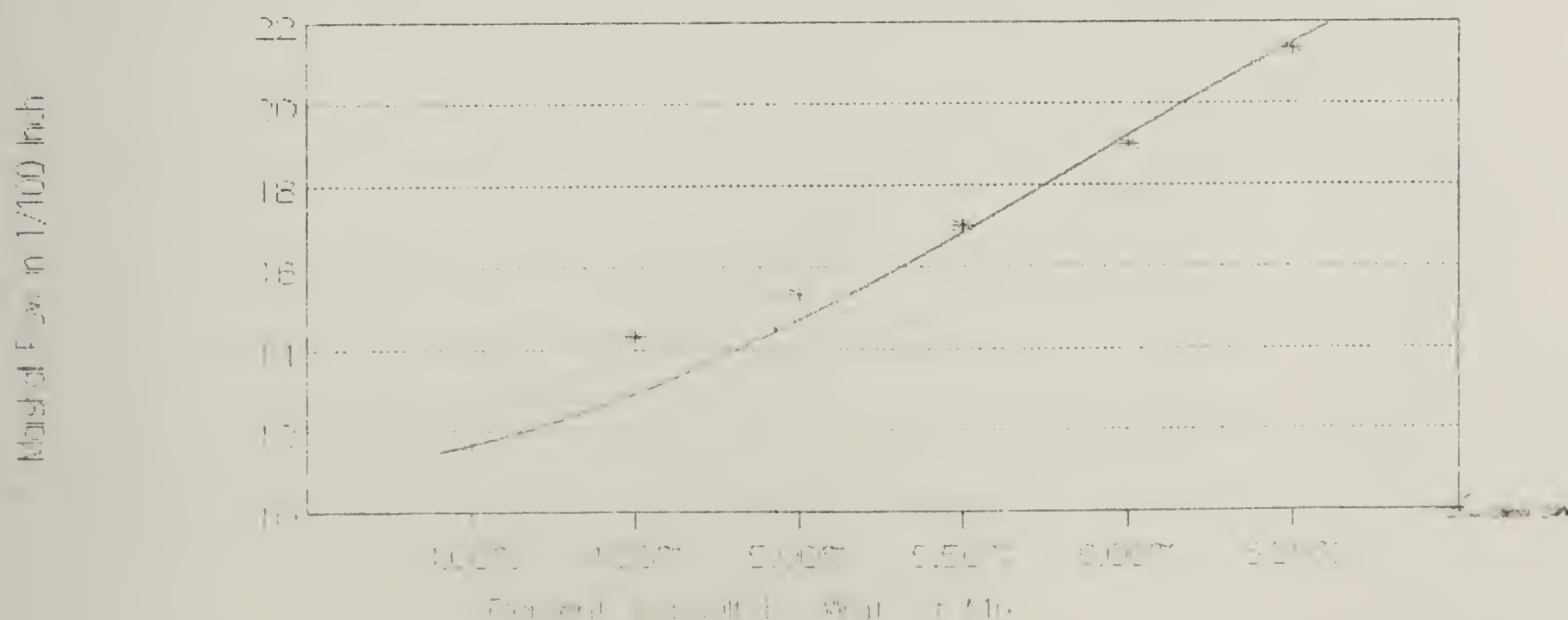
# Polybilt Mod. Cenex — I Gradation Agg.

112 Blows — Marshall Stability in lbs.



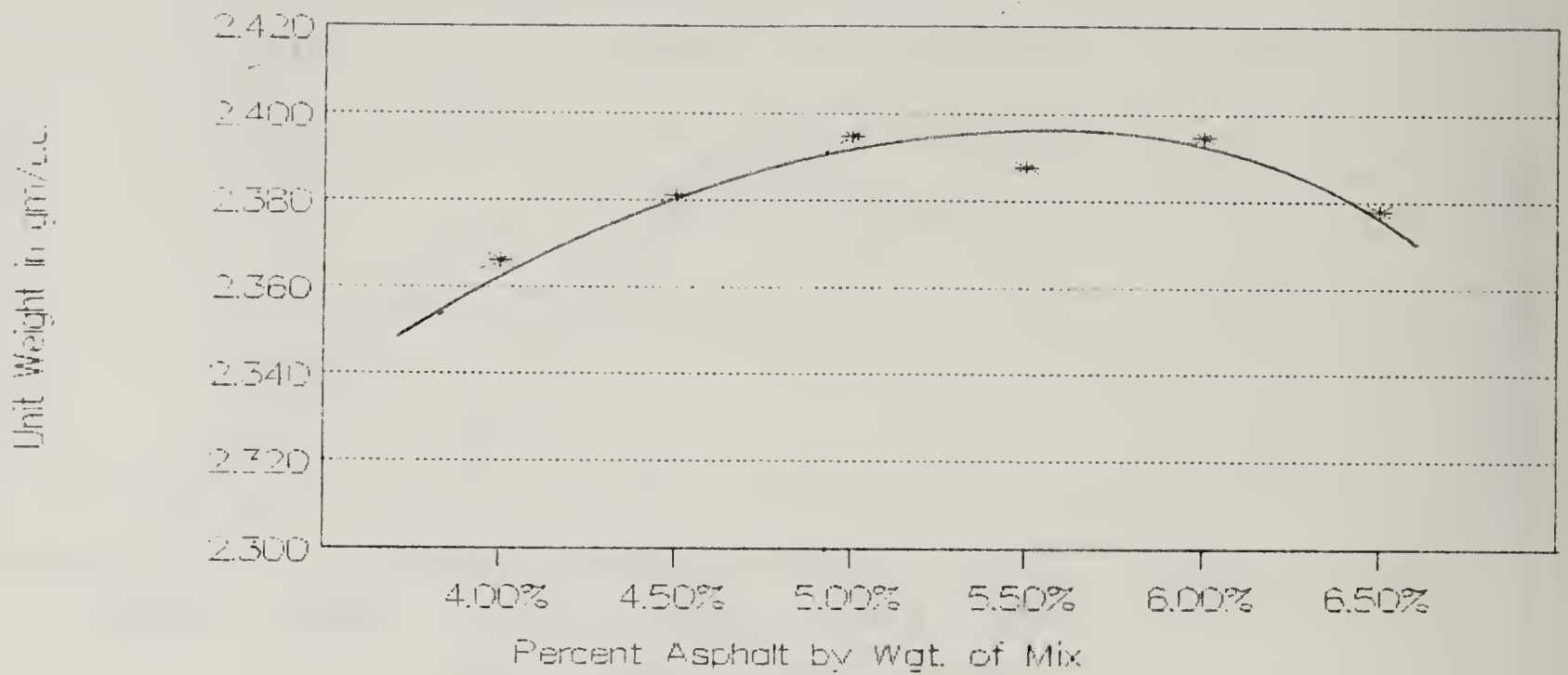
# Polybilt Mod. Cenex — I Gradation Agg.

112 Blows — Marshall Flow in 1/100 Inch



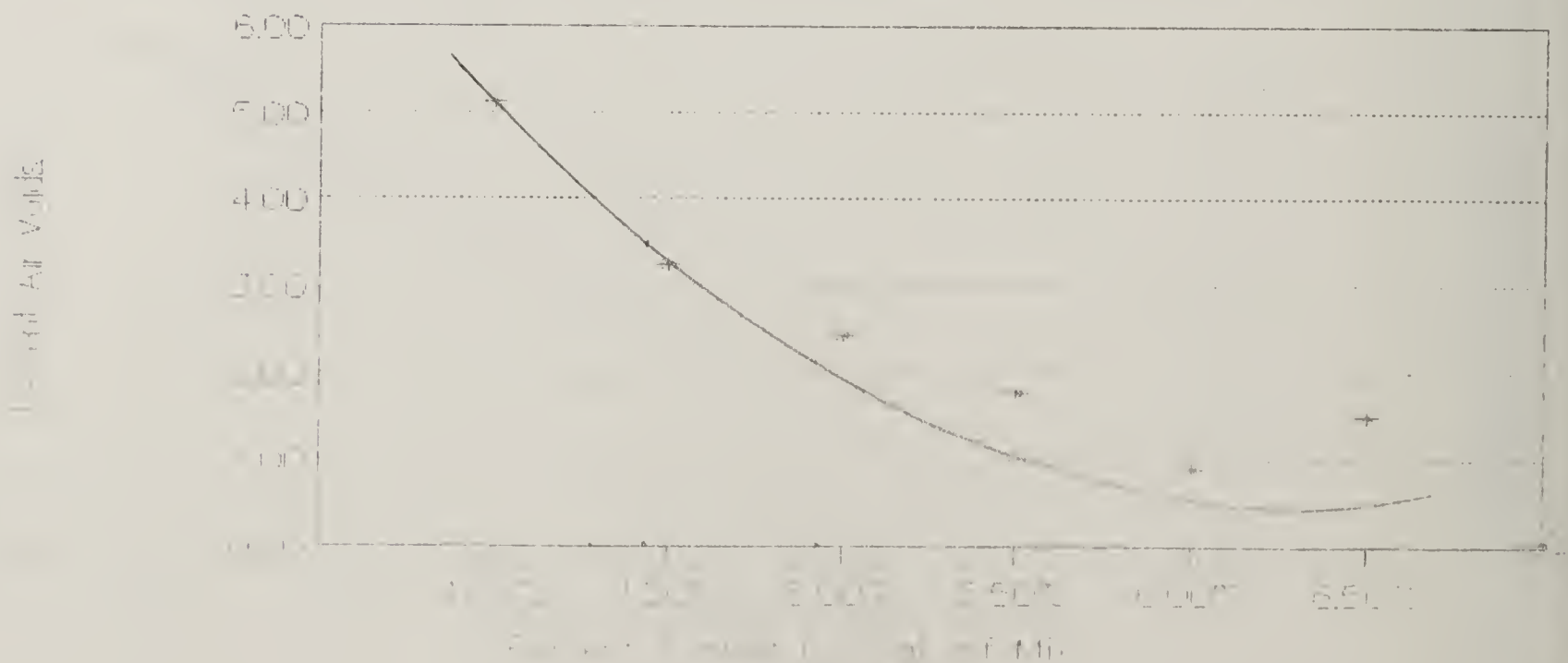
# Polybilt Mod. Cenex - I Gradation Agg.

112 Blows - Unit Weight gm/c.c.



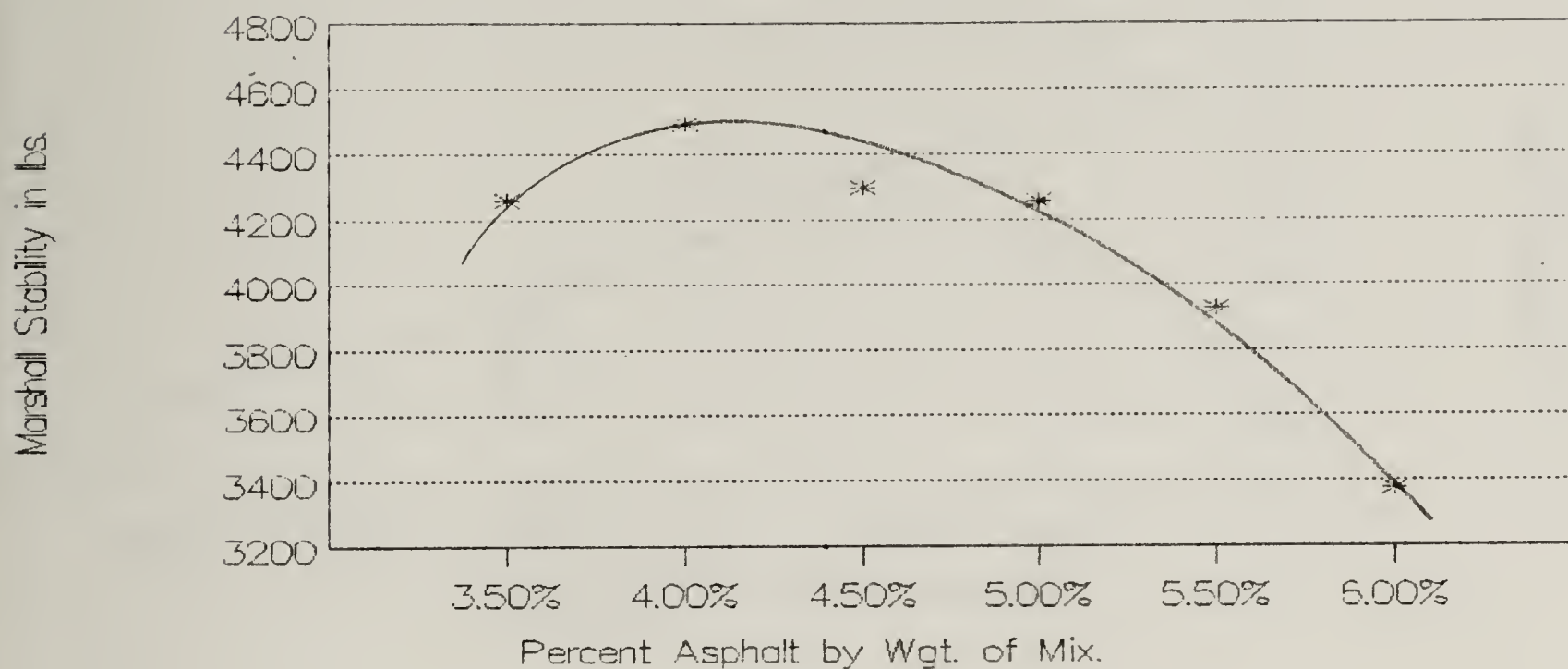
# Polybilt Mod. Cenex - I Gradation Agg.

112 Blows - Percent Air Voids.



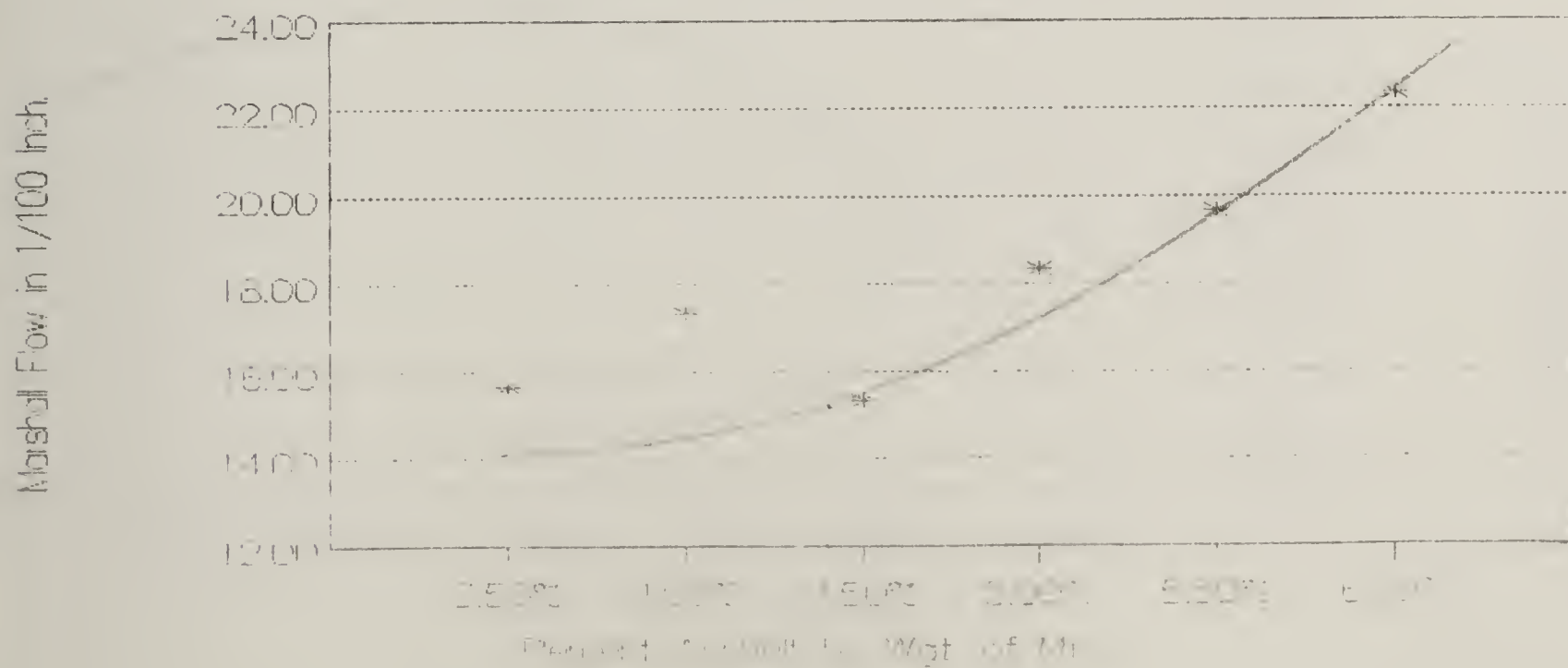
## Unmodified Cenex - I Gradation Agg.

### Miller Filler - Marshall Stability.



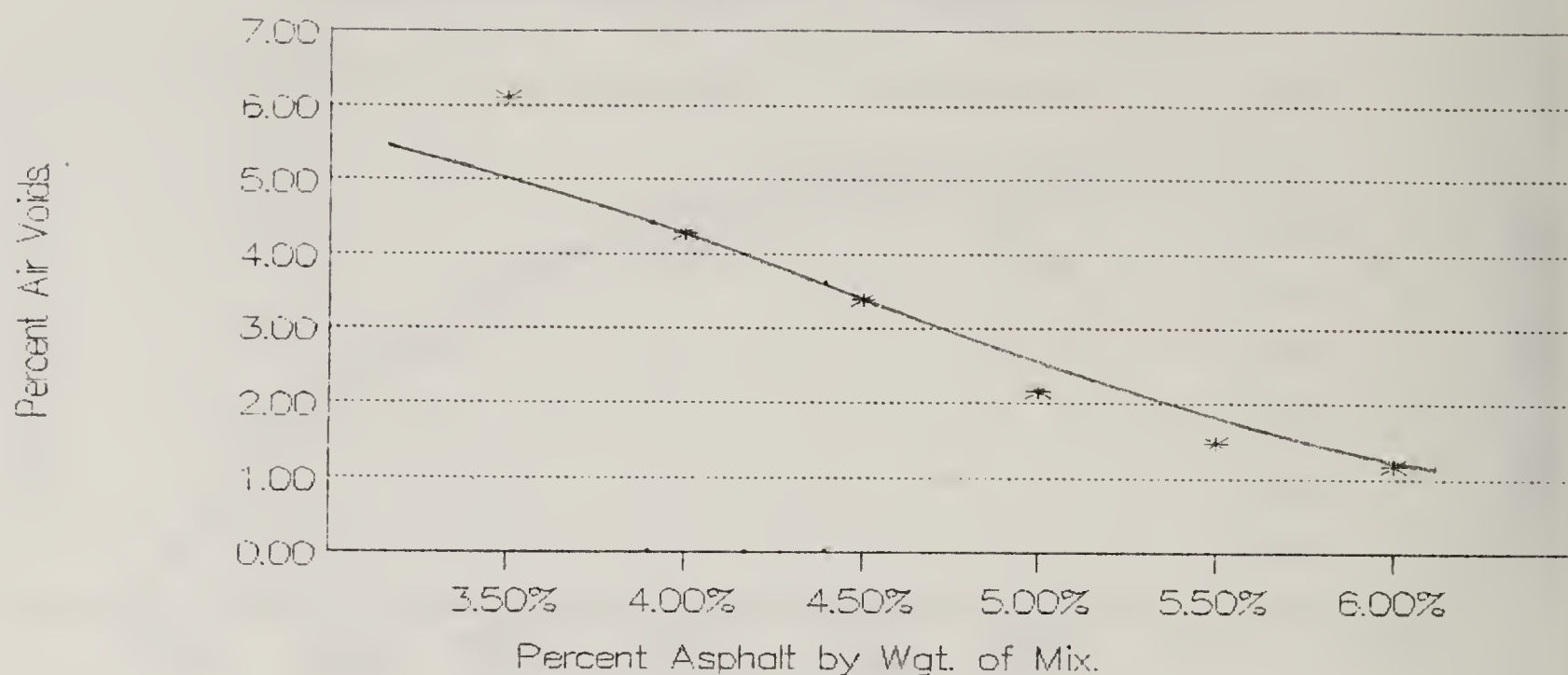
## Unmodified Cenex - I Gradation Agg.

### Miller Filler - Marshall Flow.



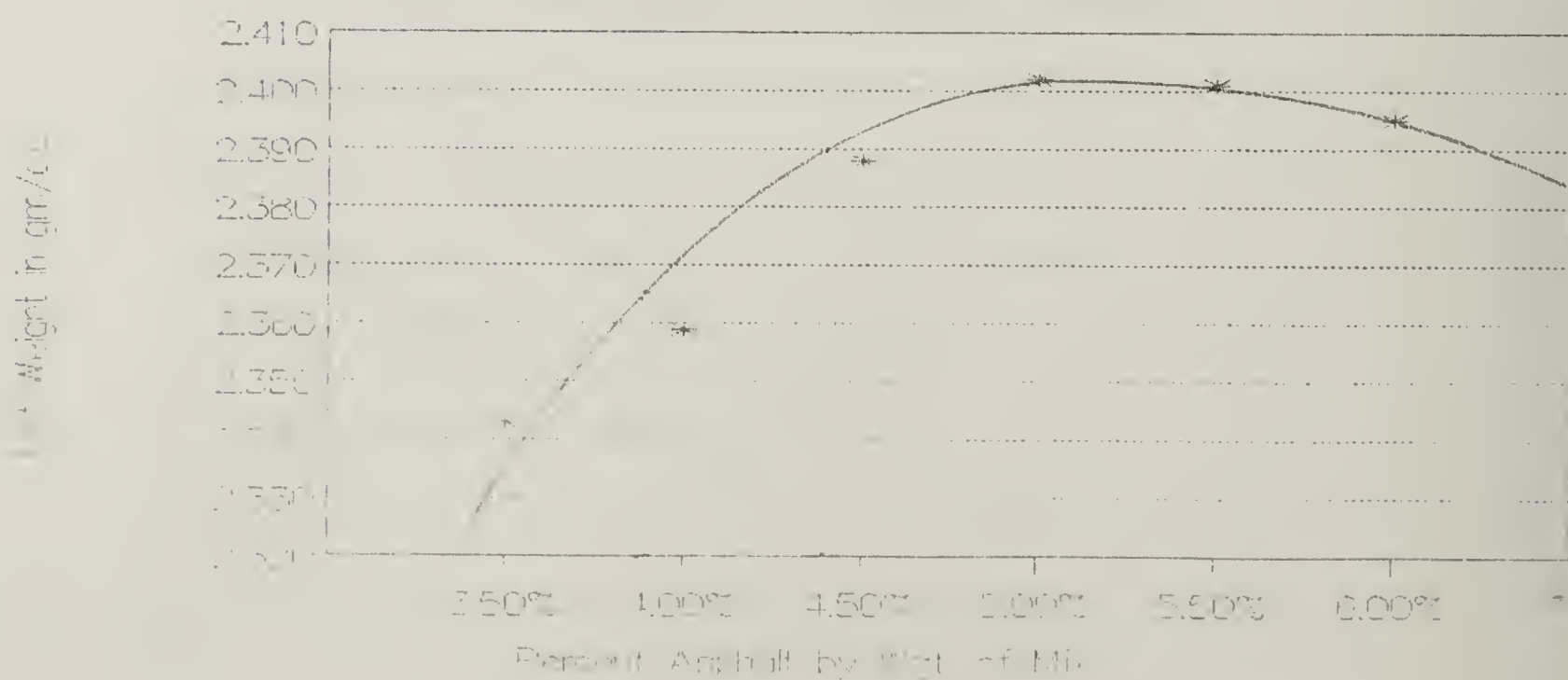
# Unmodified Cenex - I Gradation Agg.

## Miller Filler - Percent Air Voids.



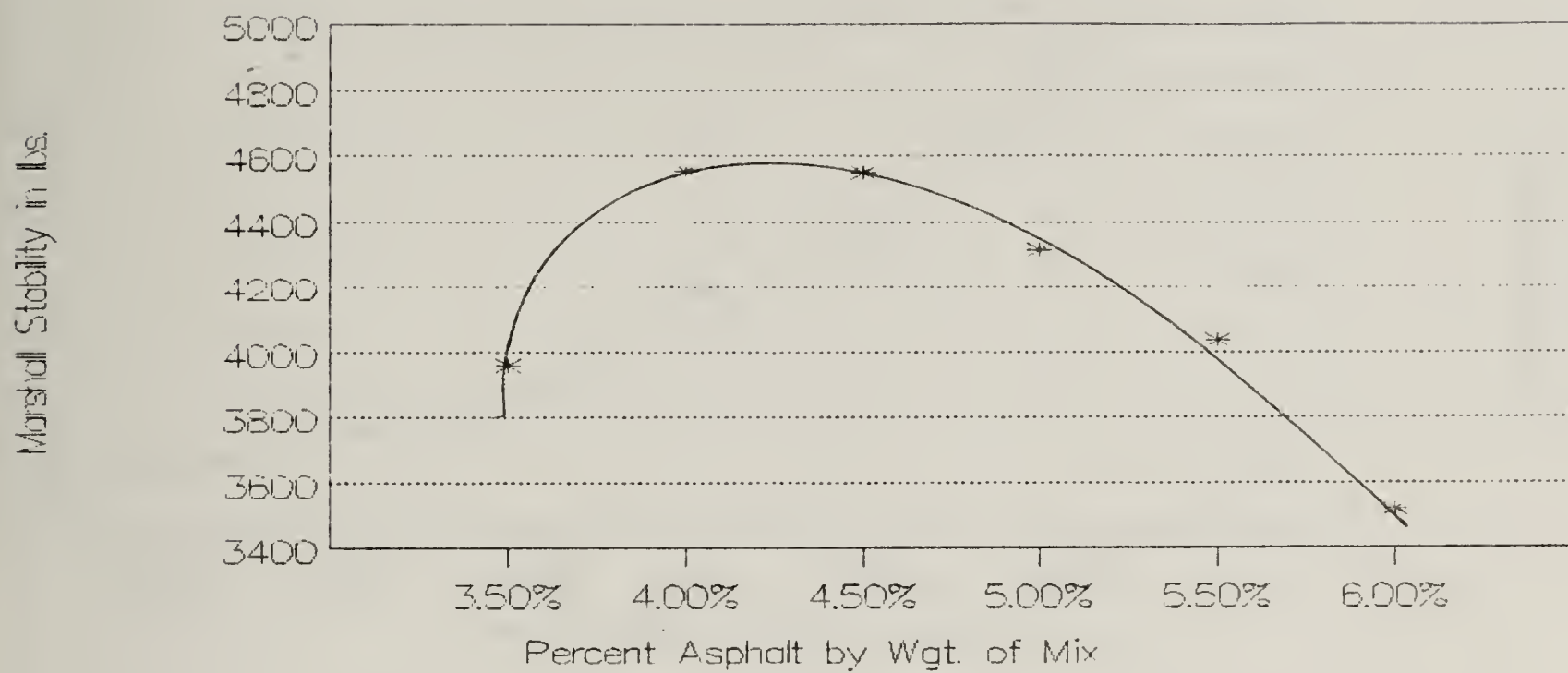
# Unmodified Cenex - I Gradation Agg.

## Miller Filler - Unit Weight in gm/c.c.



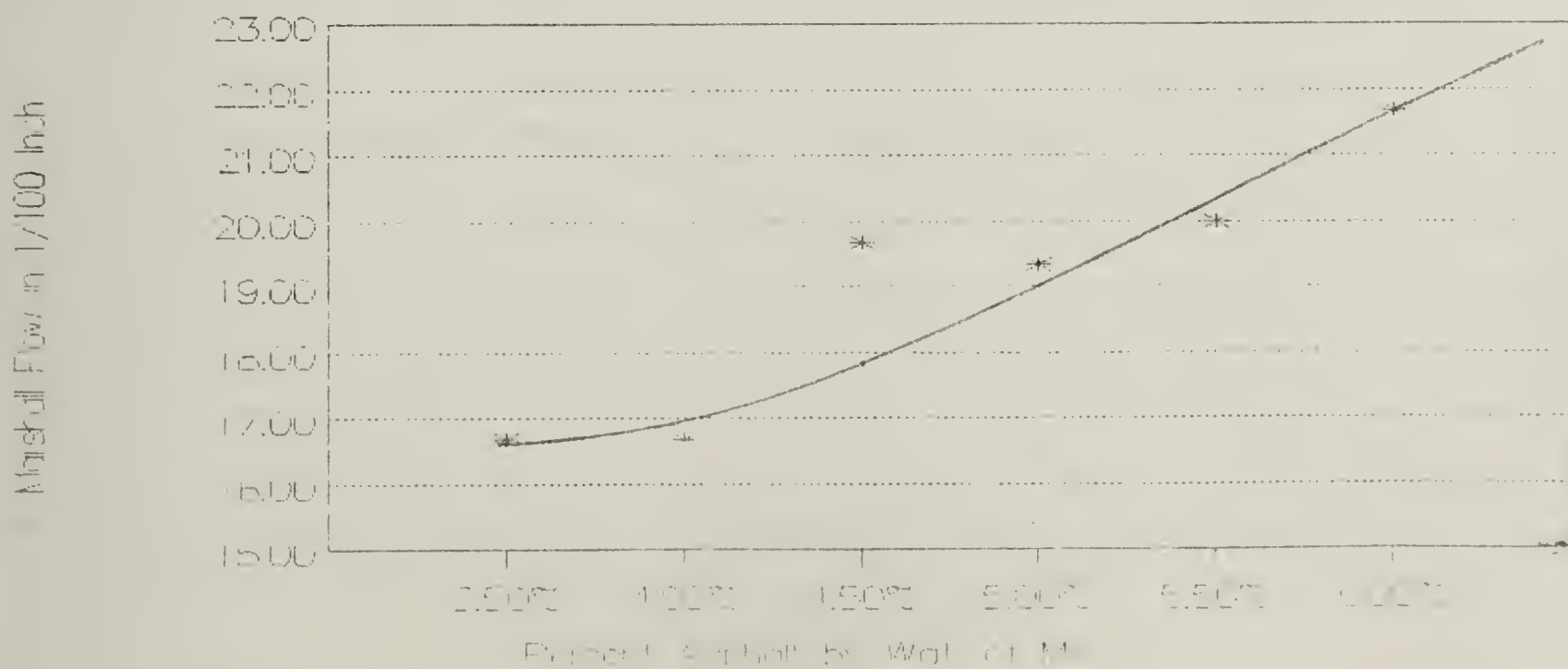
# Kraton Mod. Cenex - I Gradation Agg.

## Mineral Filler - Marshall Stability.



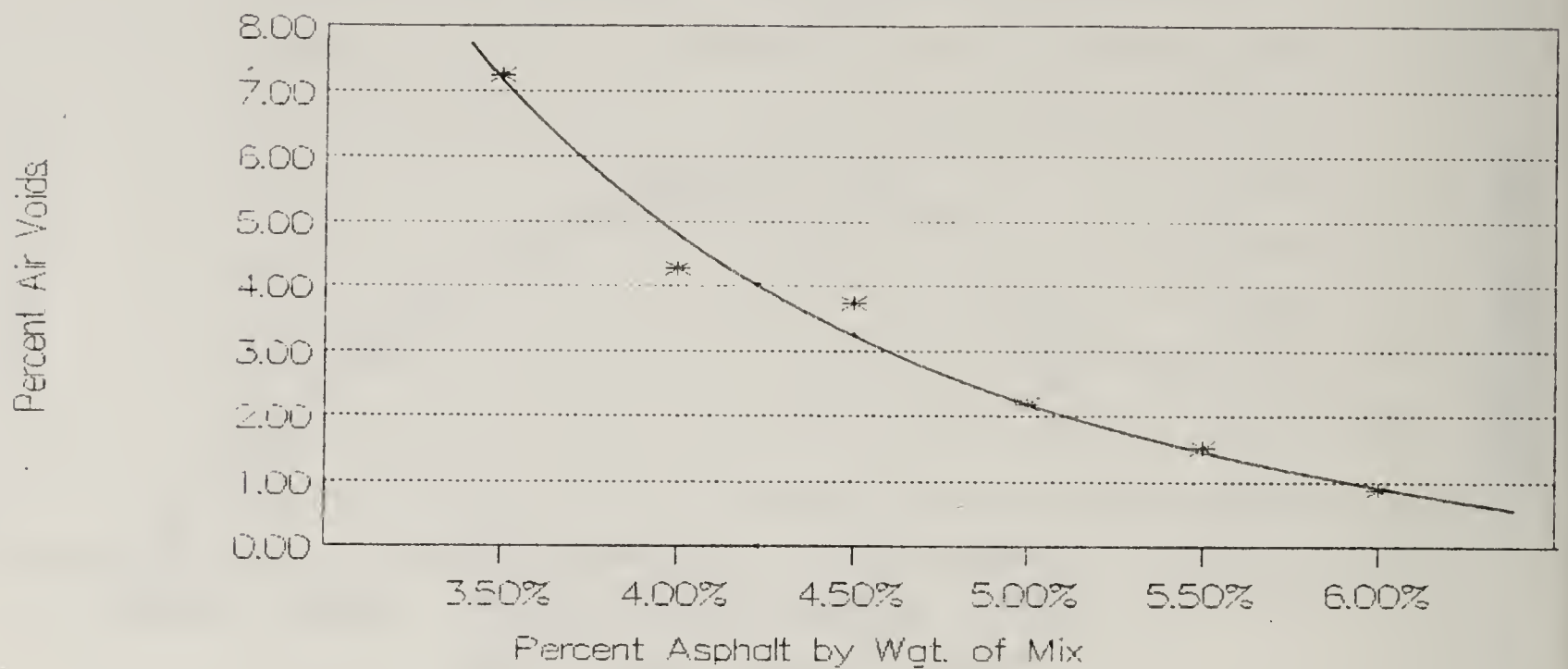
# Kraton Mod. Cenex - I Gradation Agg.

## Mineral Filler - Marshall Flow 1/100 in



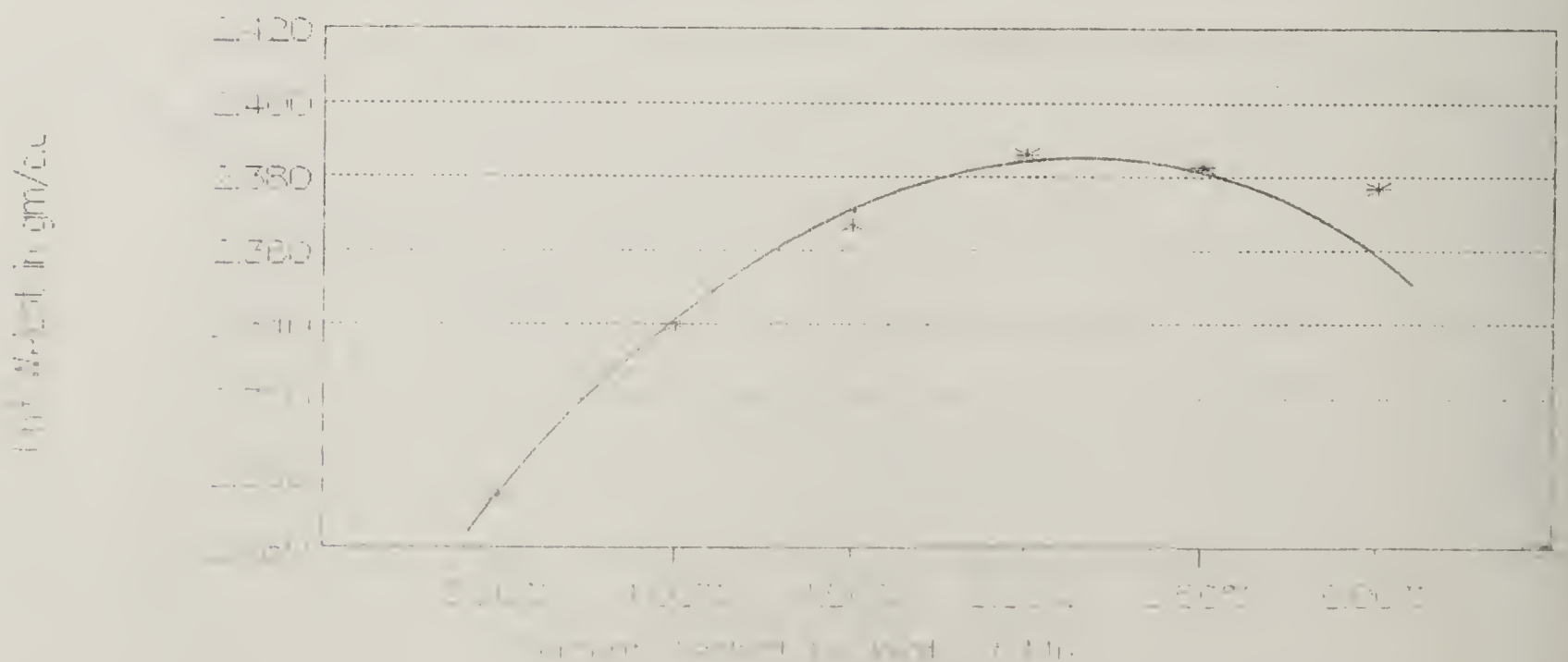
# Kraton Mod. Cenex — I Gradation Agg.

## Mineral Filler — Percent Air Voids.



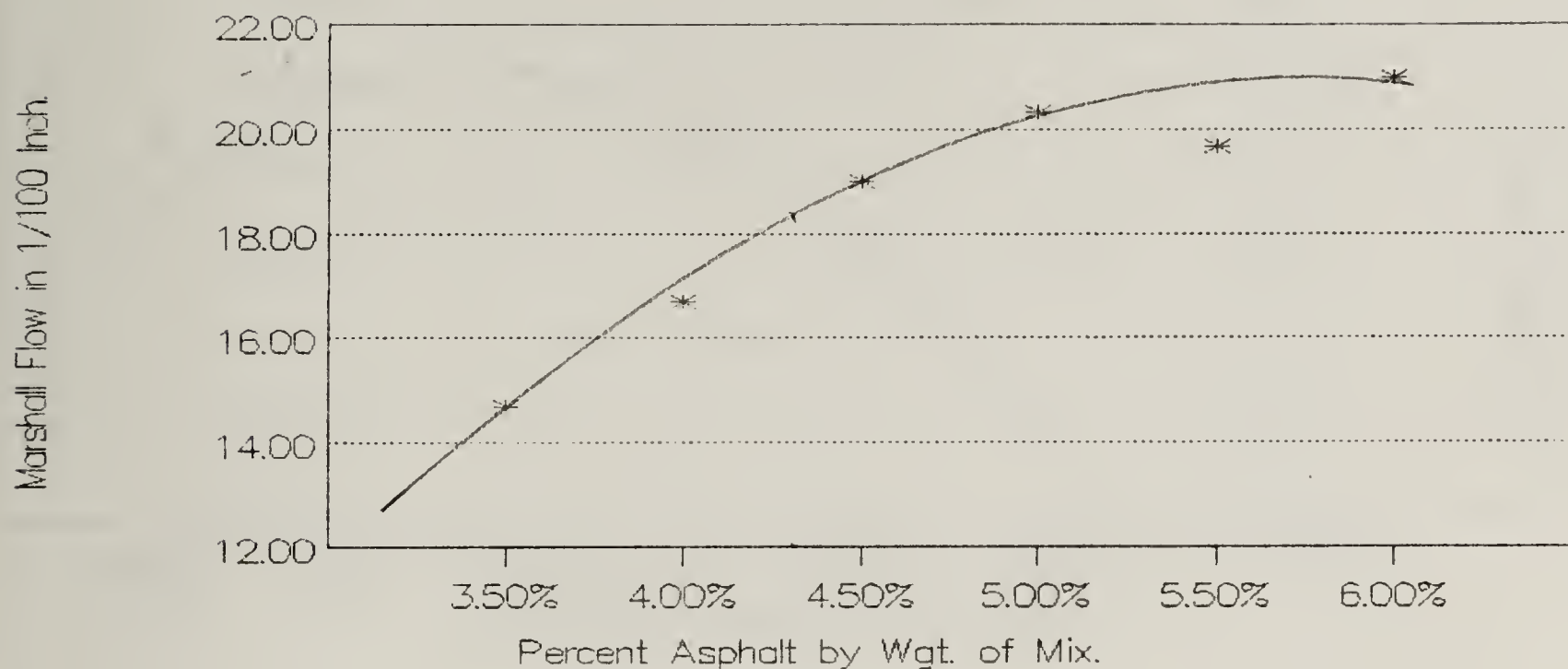
# Kraton Mod. Cenex — I Gradation Agg.

## Mineral Filler — Unit Weight in gm/c.c.



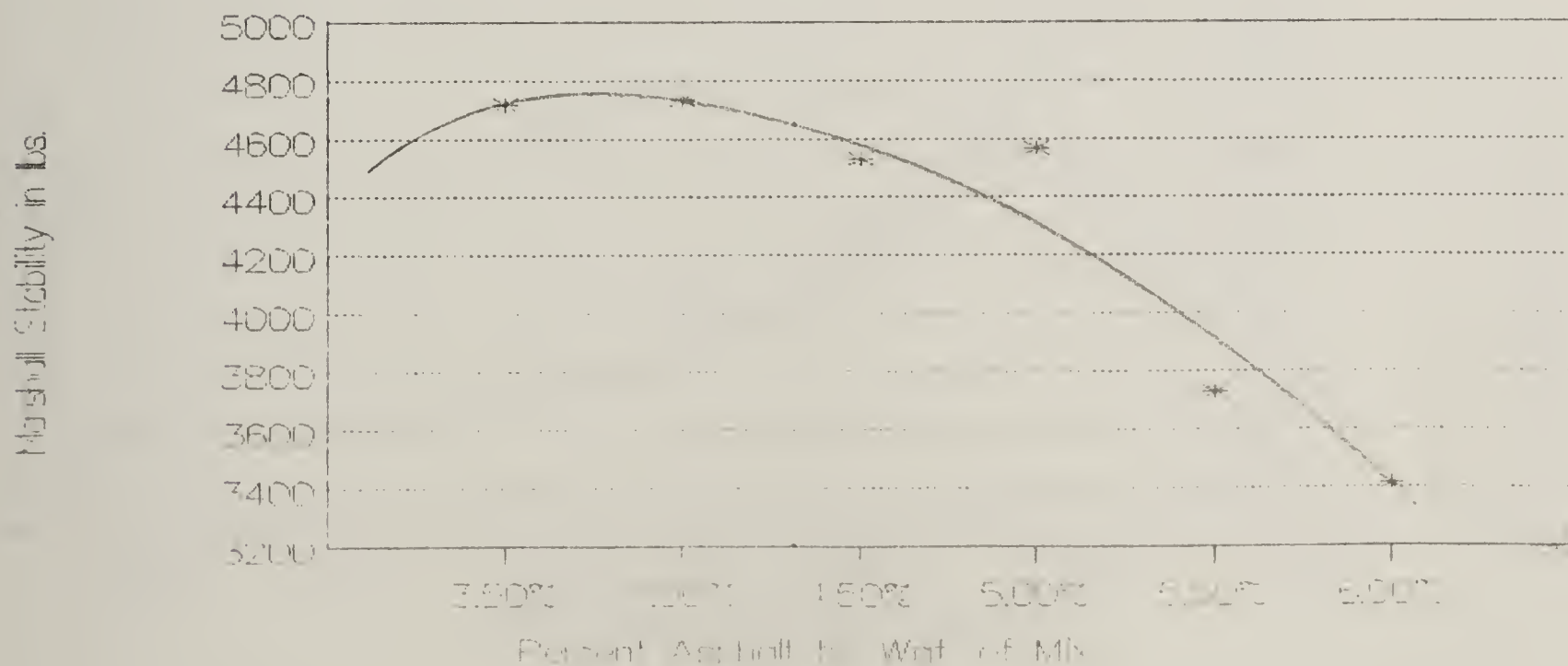
# Polybilt Mod. Cenex - I Gradation Agg.

## Miller Filler - Marshall Flow.



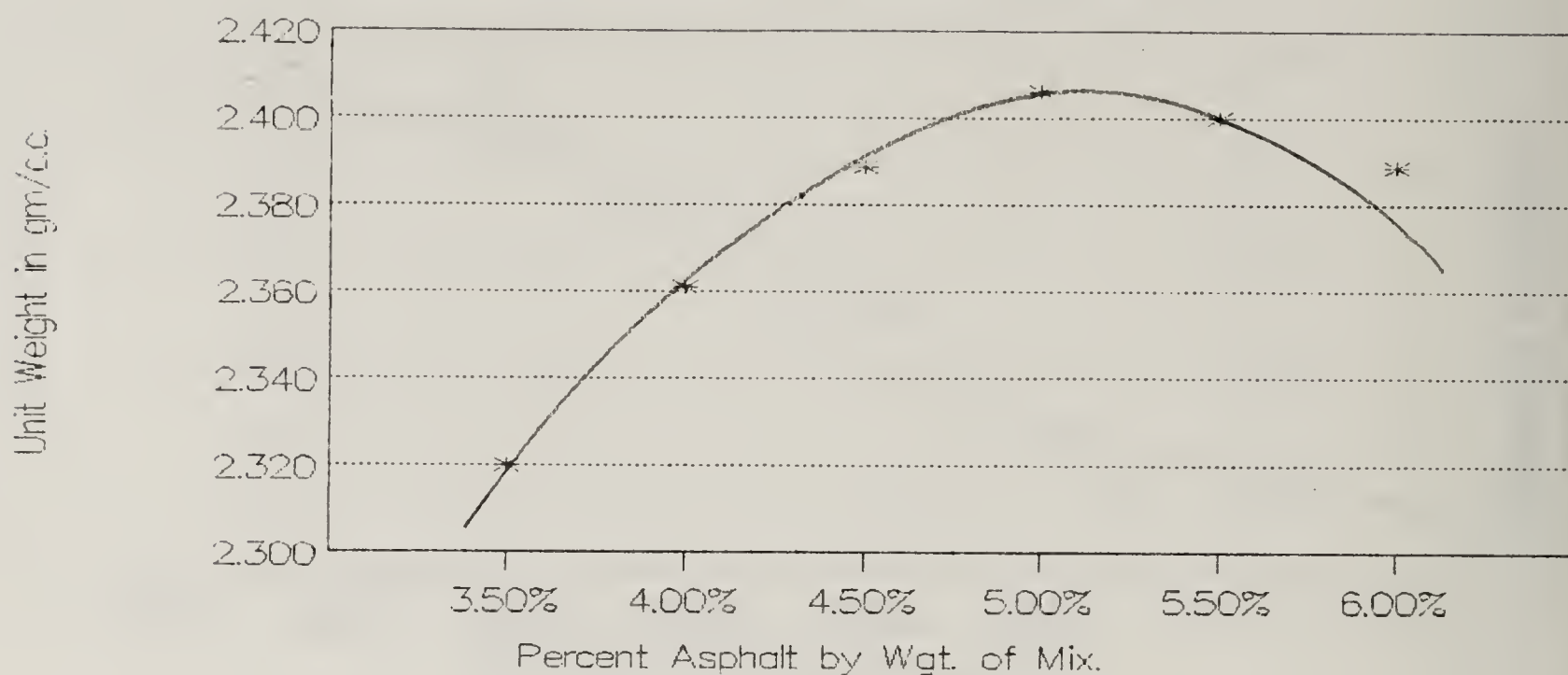
# Polybilt Mod. Cenex - I Gradation Agg.

## Miller Filler - Marshall Stability.



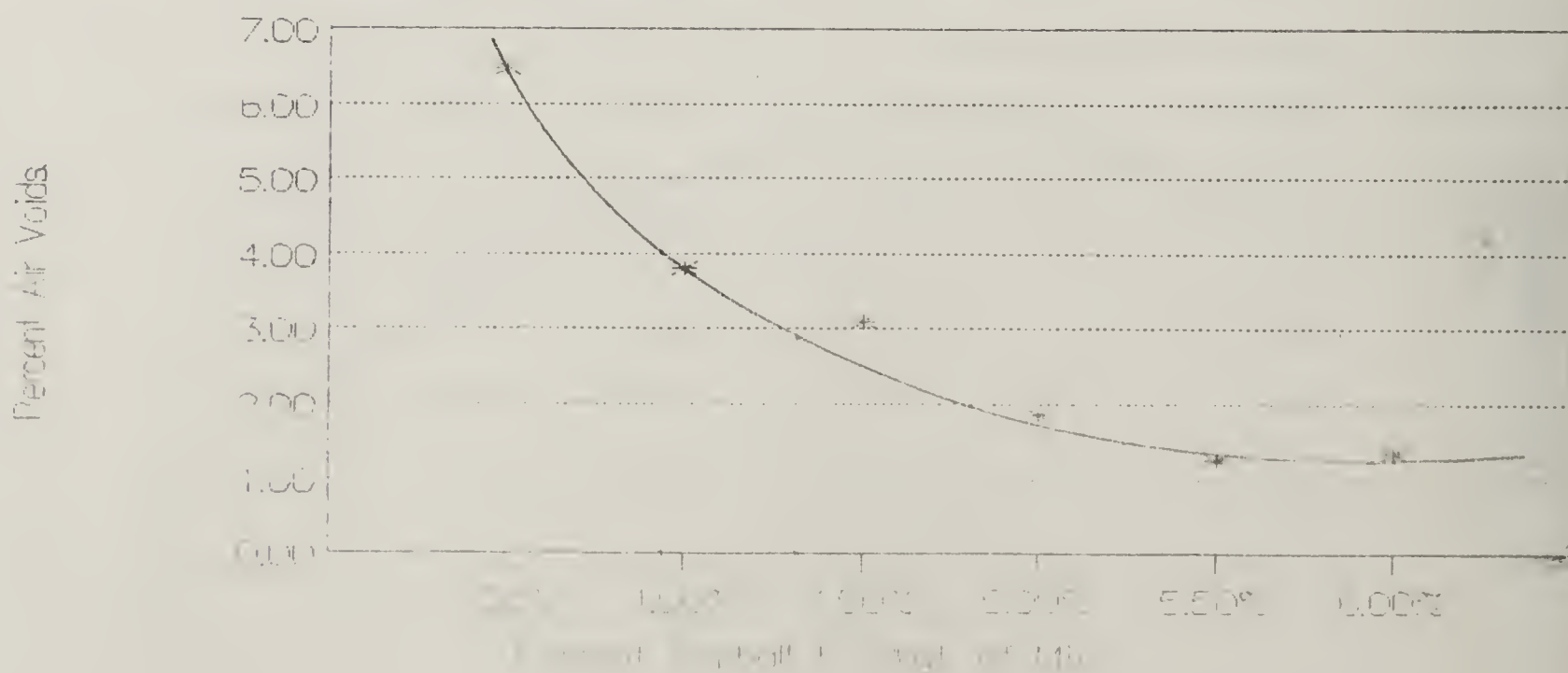
# Polybilt Mod. Cenex - I Gradation Agg.

Miller Filler - Unit Weight in gm/c.c.



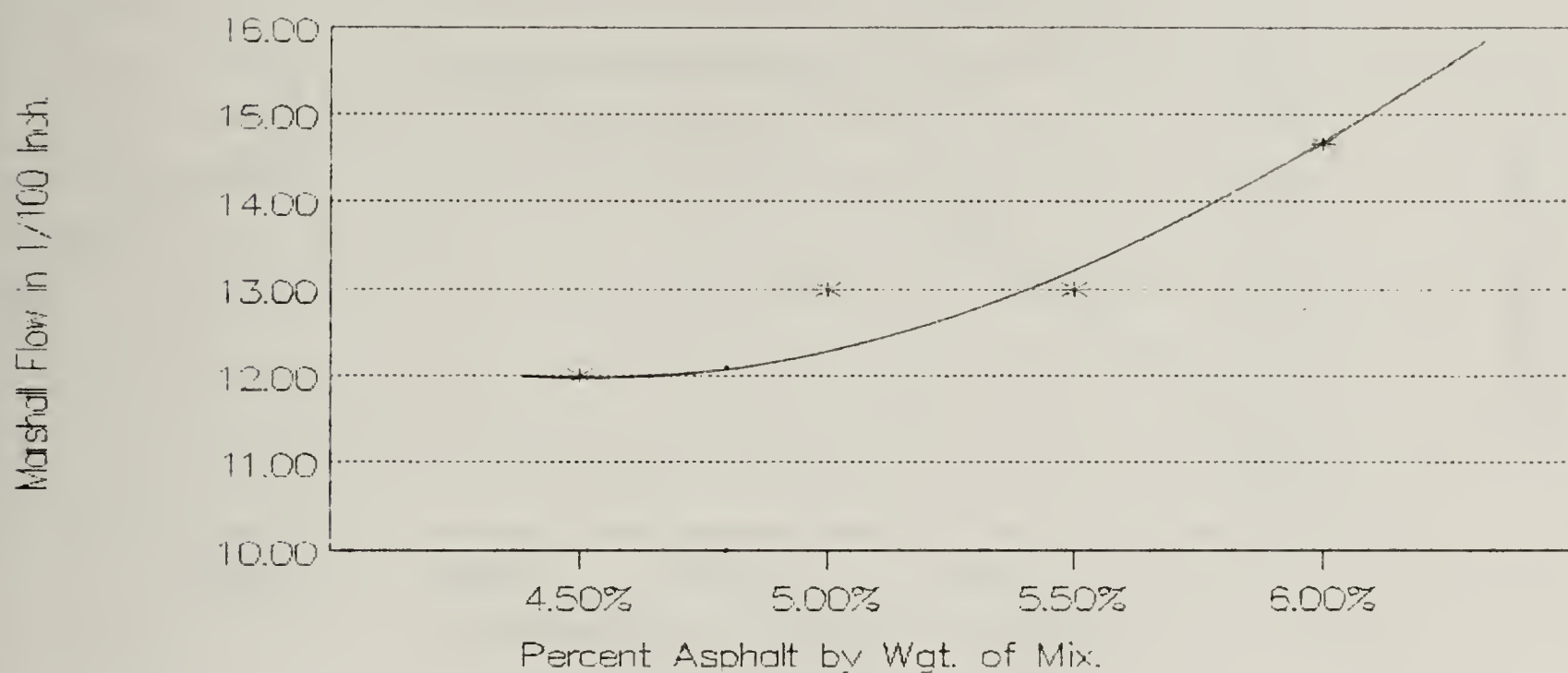
# Polybilt Mod. Cenex - I Gradation Agg.

Miller Filler - Percent Air Voids.



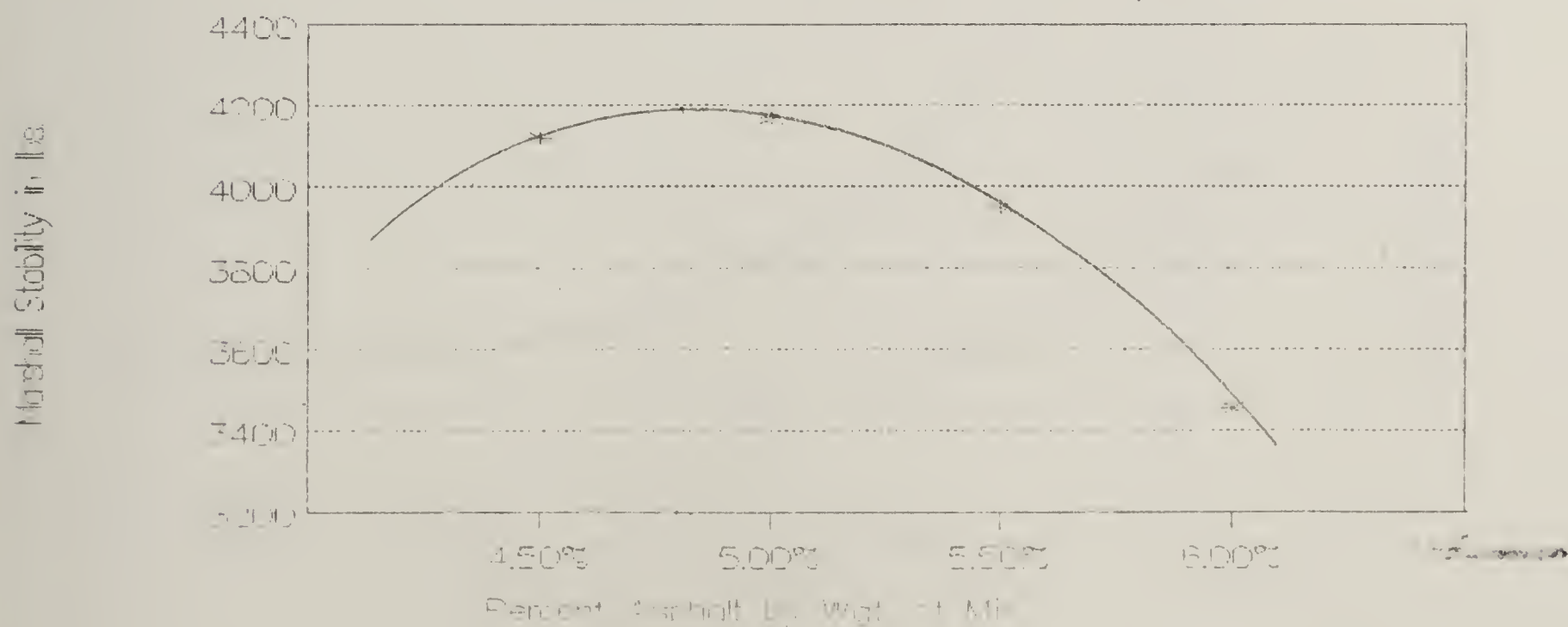
# Unmodified Conoco - I Gradation Agg.

75 Blow - Marshall Flow.



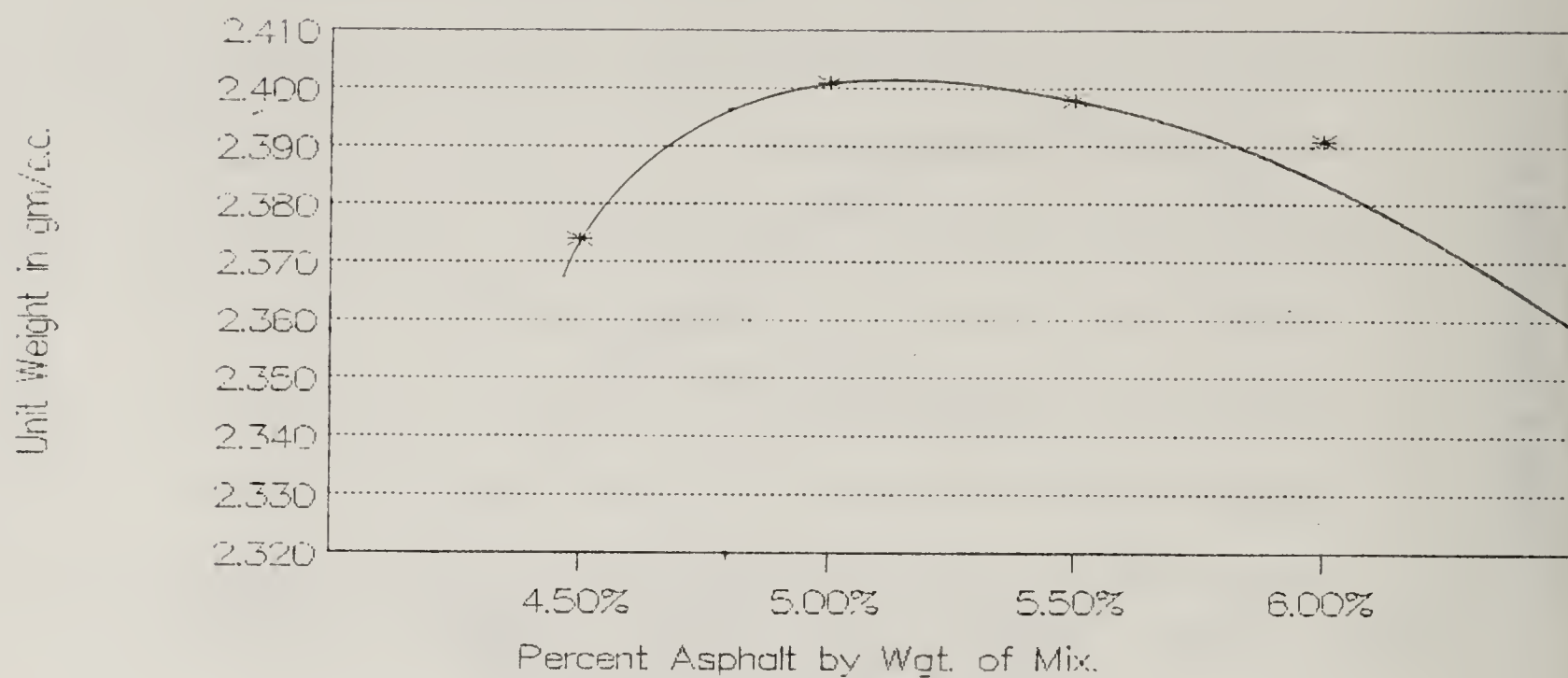
# Unmodified Conoco - I Gradation Agg.

75 Blow - Marshall Stability.



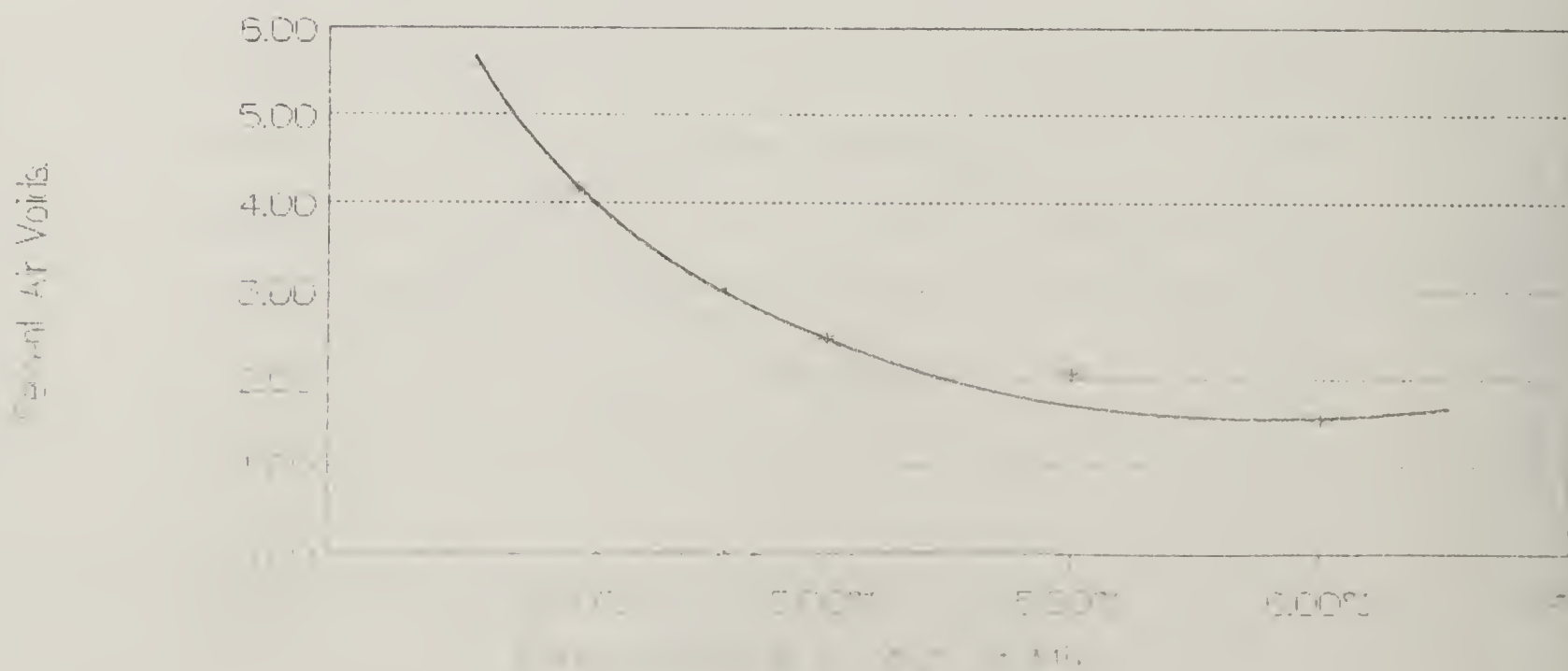
# Unmodified Conoco - I Gradation Agg.

75 Blow - Unit Weight in gm/c.c.



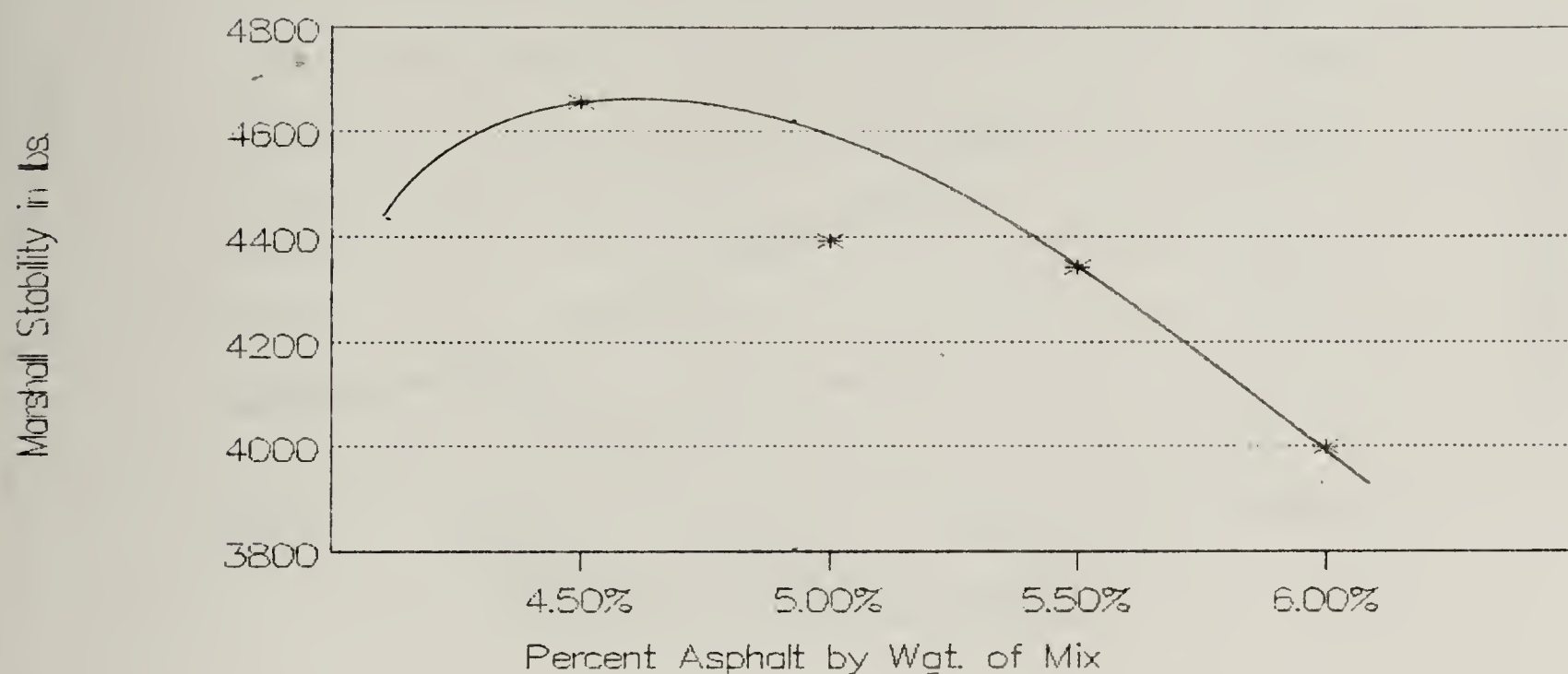
# Unmodified Conoco - I Gradation Agg.

75 Blow - Percent Air Voids.



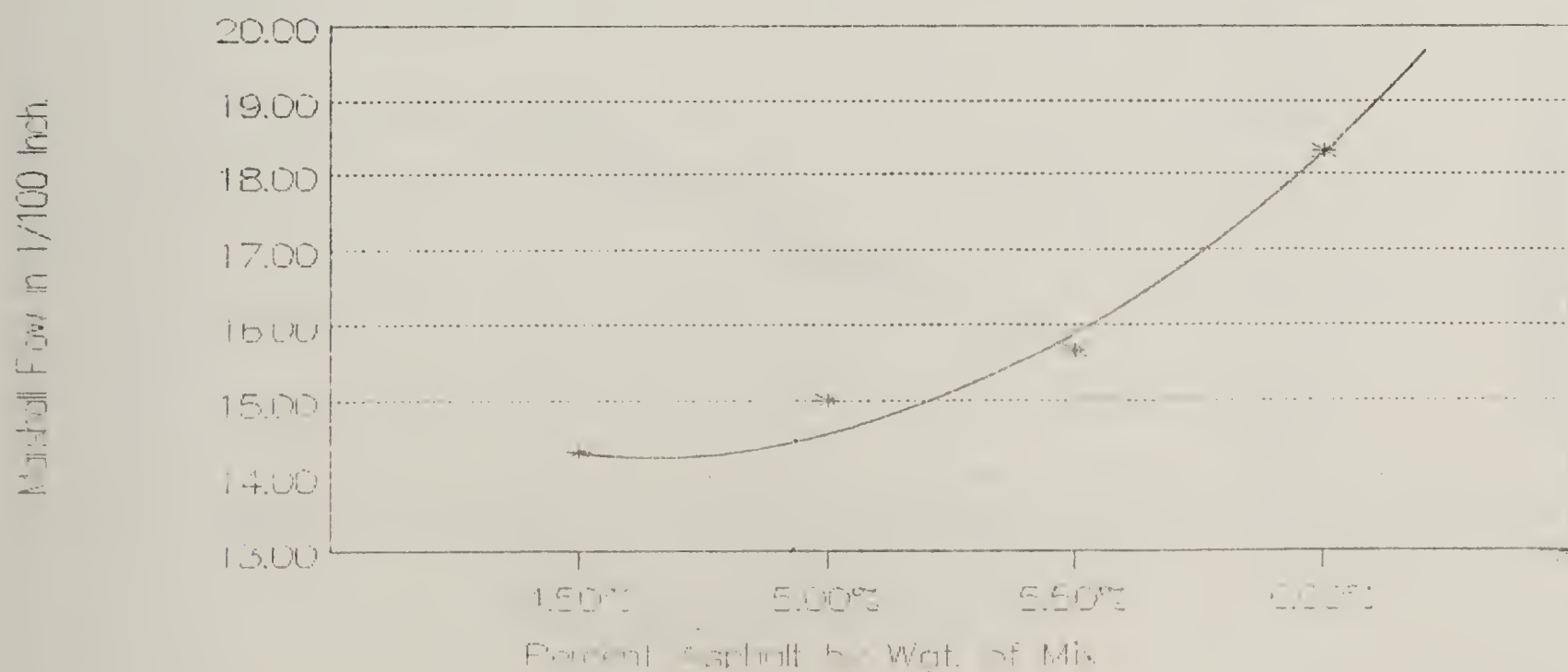
# Kraton Mod. Conoco - I Gradation Agg.

75 Blow - Marshall Stability in lbs.



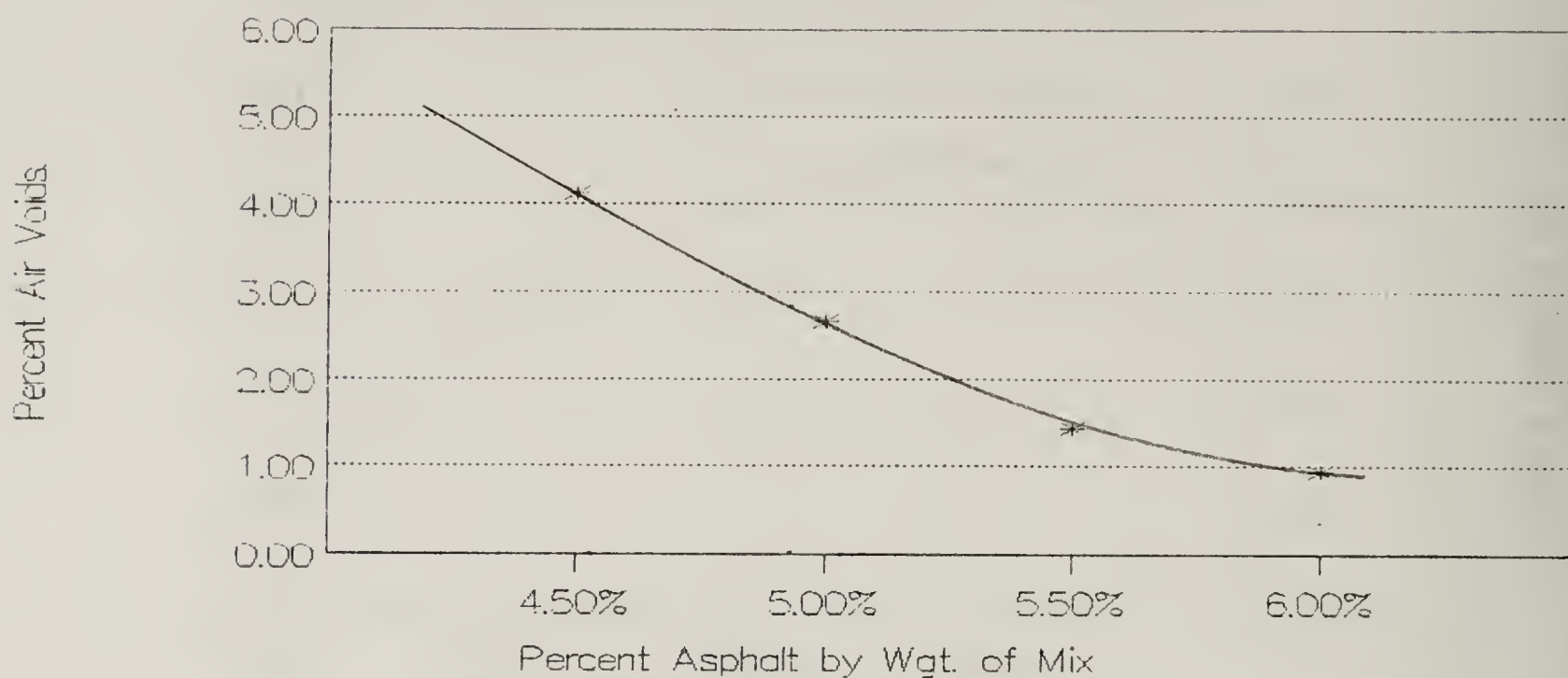
# Kraton Mod. Conoco - I Gradation Agg.

75 Blow - Marshall Flow in 1/100 Inch.



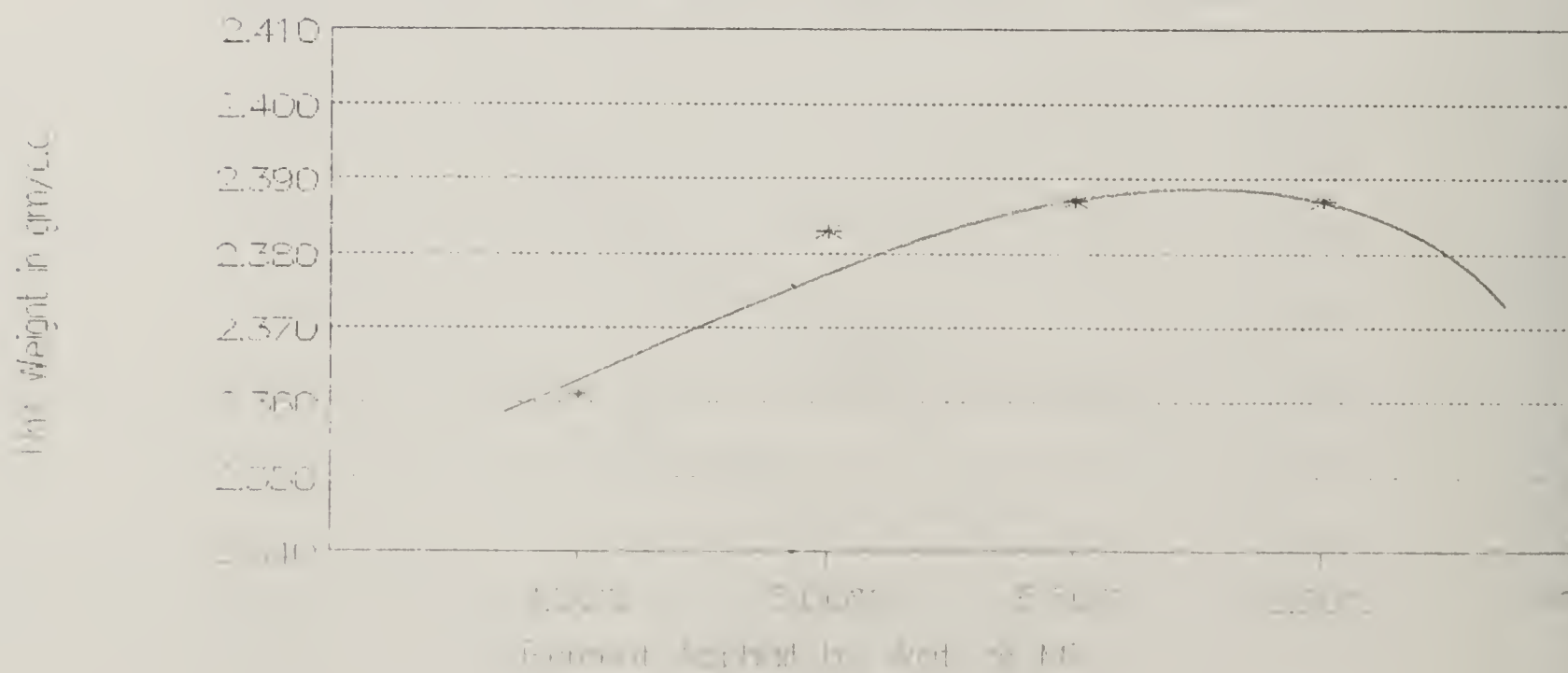
# Kraton Mod. Conoco - I Gradation Agg.

75 Blow - Percent Air Voids.



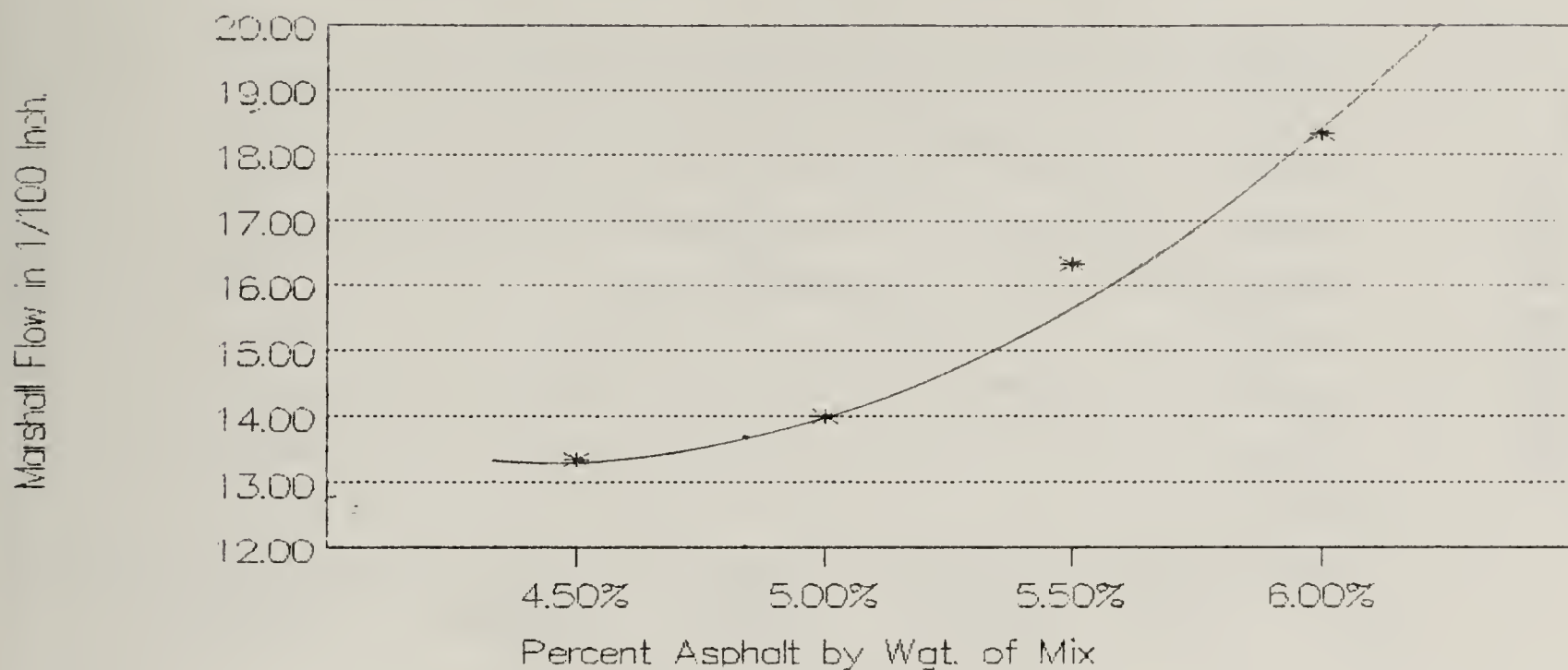
# Kraton Mod. Conoco - I Gradation Agg.

75 Blow - Unit Weight in gm/c.c.



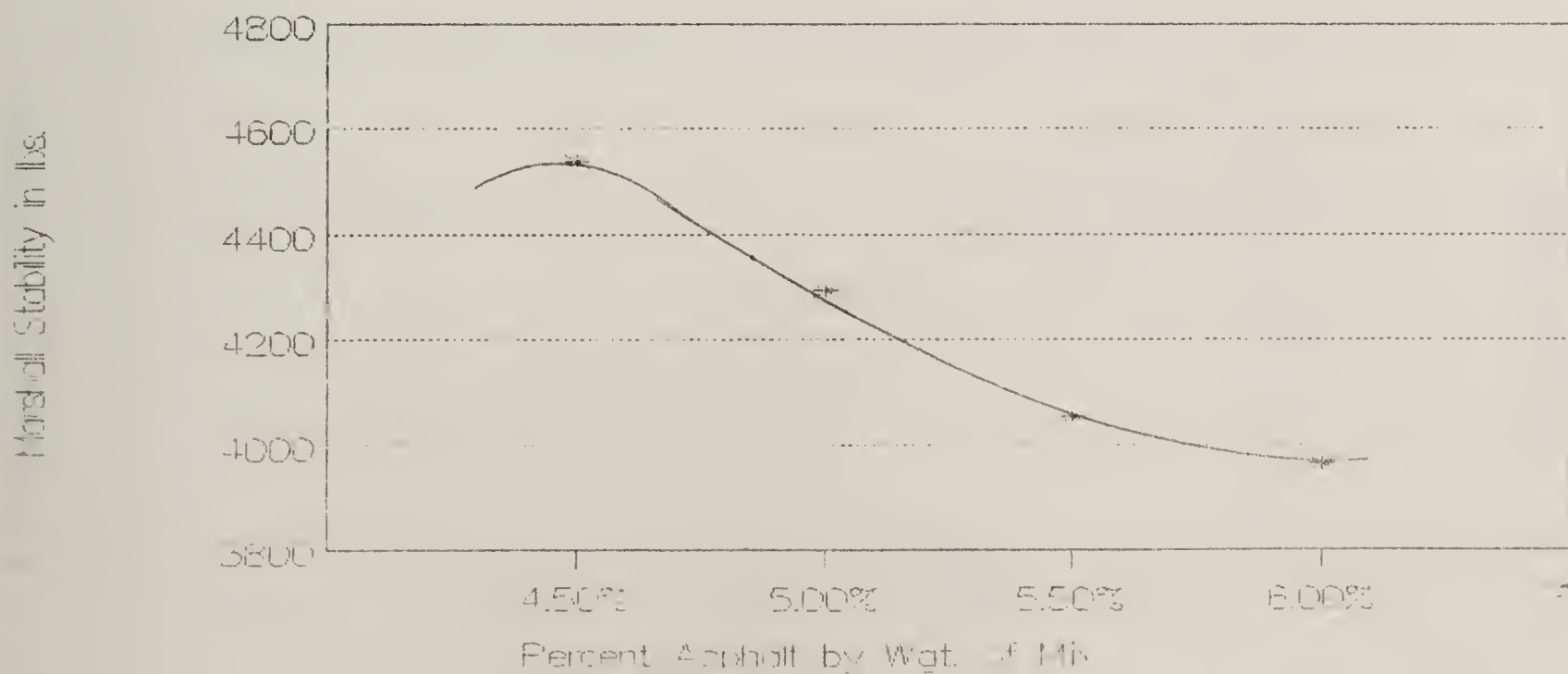
# Polybilt Mod. Conoco - I Gradation Agg.

75 Blow - Marshall Flow in 1/100 Inch.



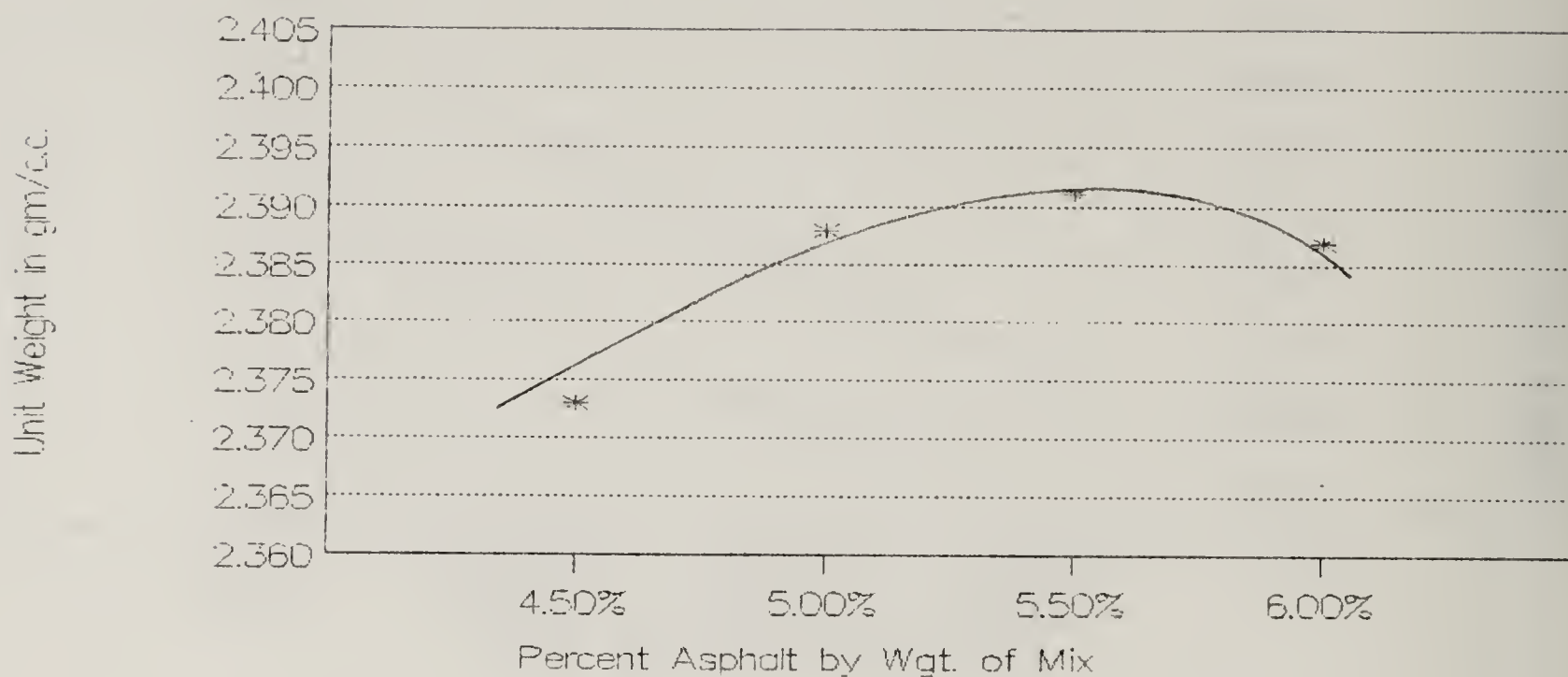
# Polybilt Mod. Conoco - I Gradation Agg.

75 Blow - Marshall Stability in lbs.



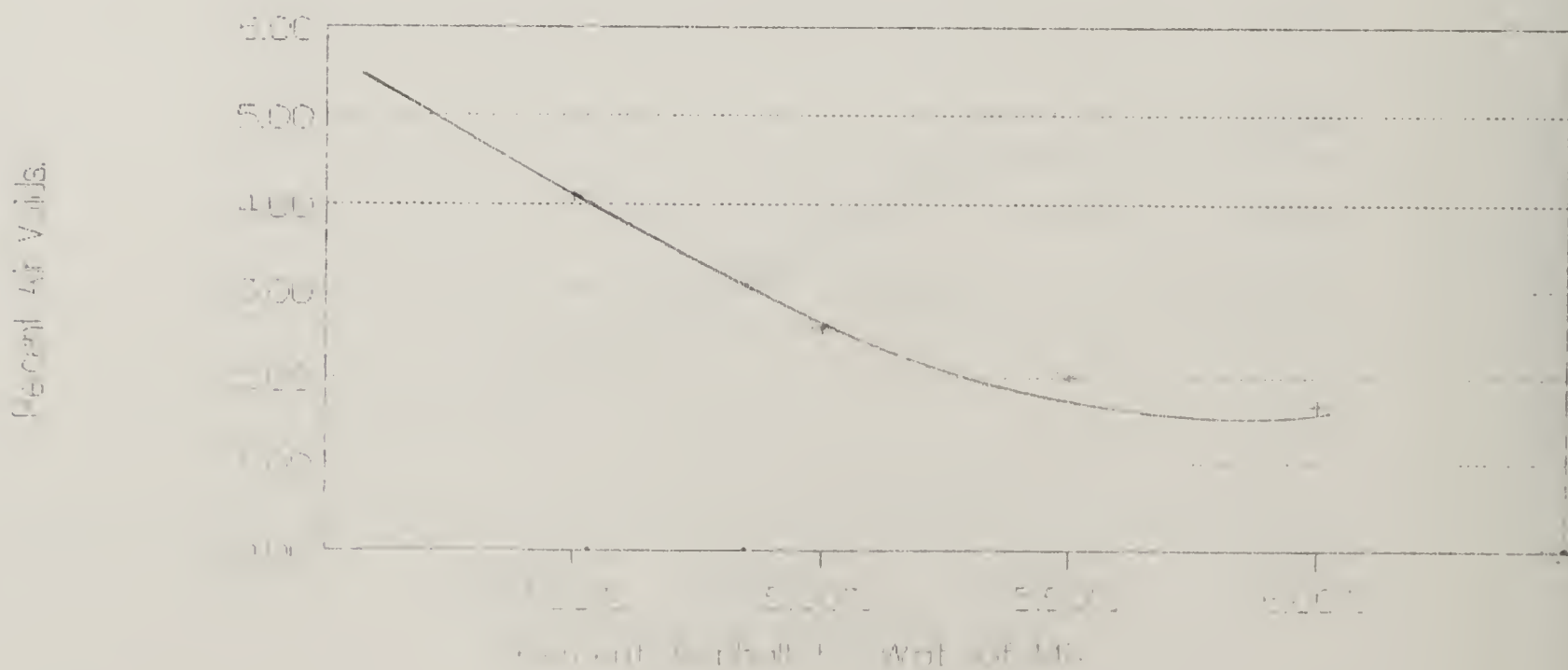
# Polybilt Mod. Conoco - I Gradation Agg.

75 Blow - Unit Weight in gm/c.c.



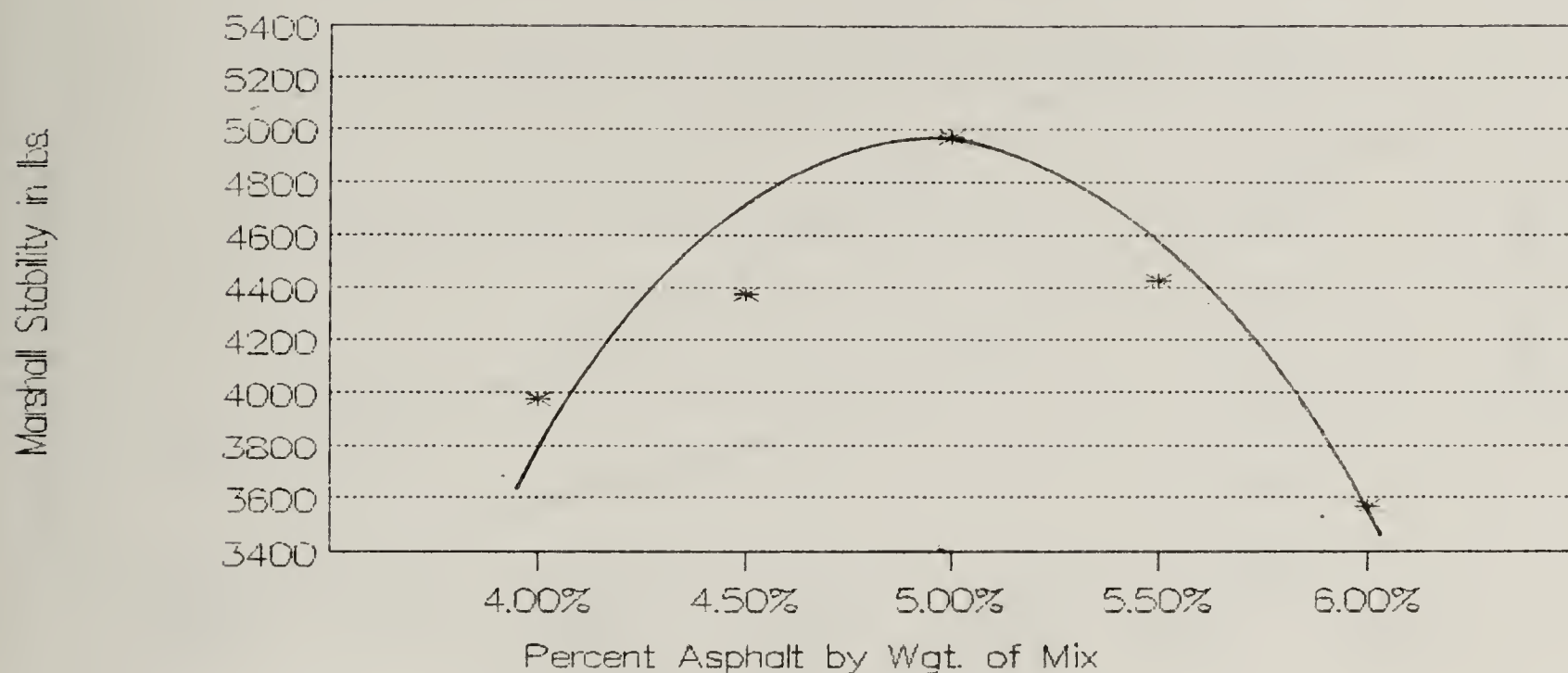
# Polybilt Mod. Conoco - I Gradation Agg.

75 Blow - Percent Air Voids.



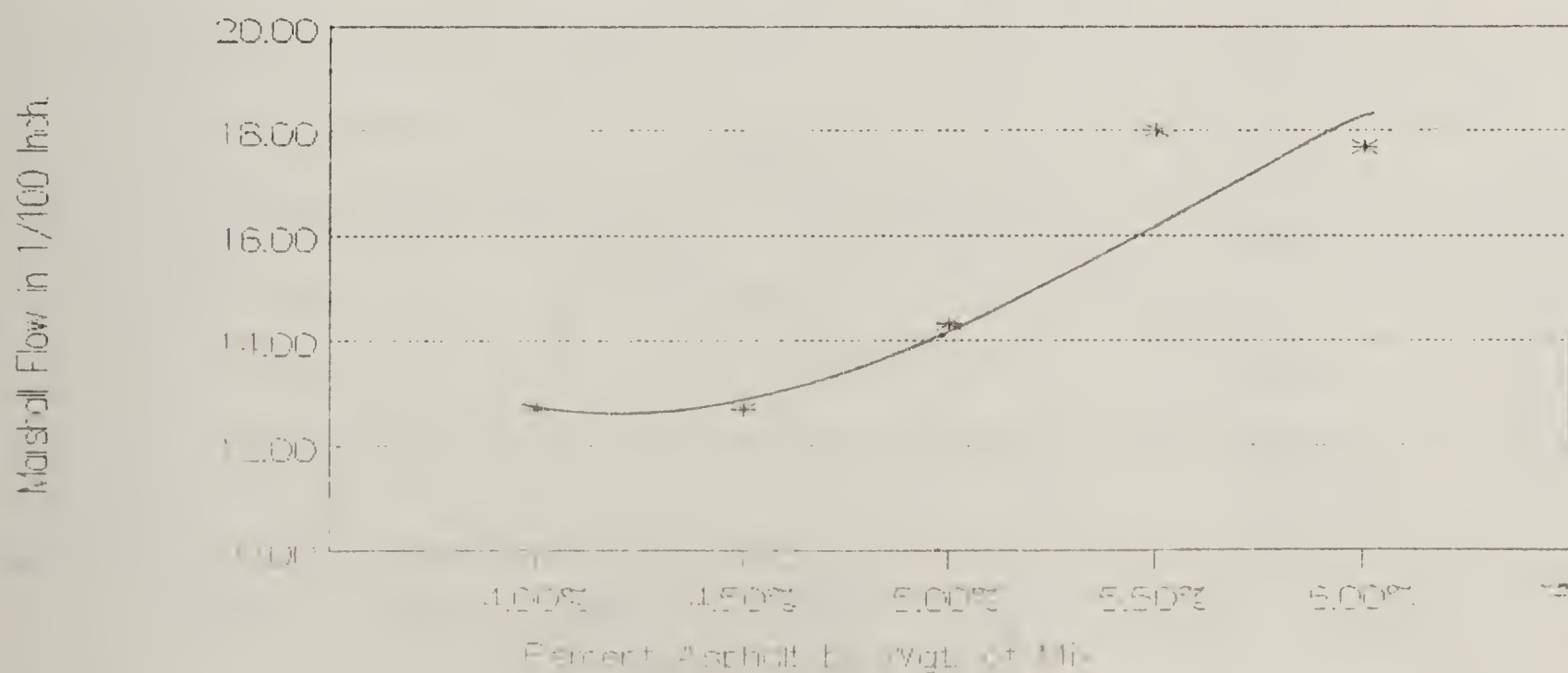
# Unmodified Conoco - I Gradation Agg.

112 Blows - Marshall Stability in lbs.



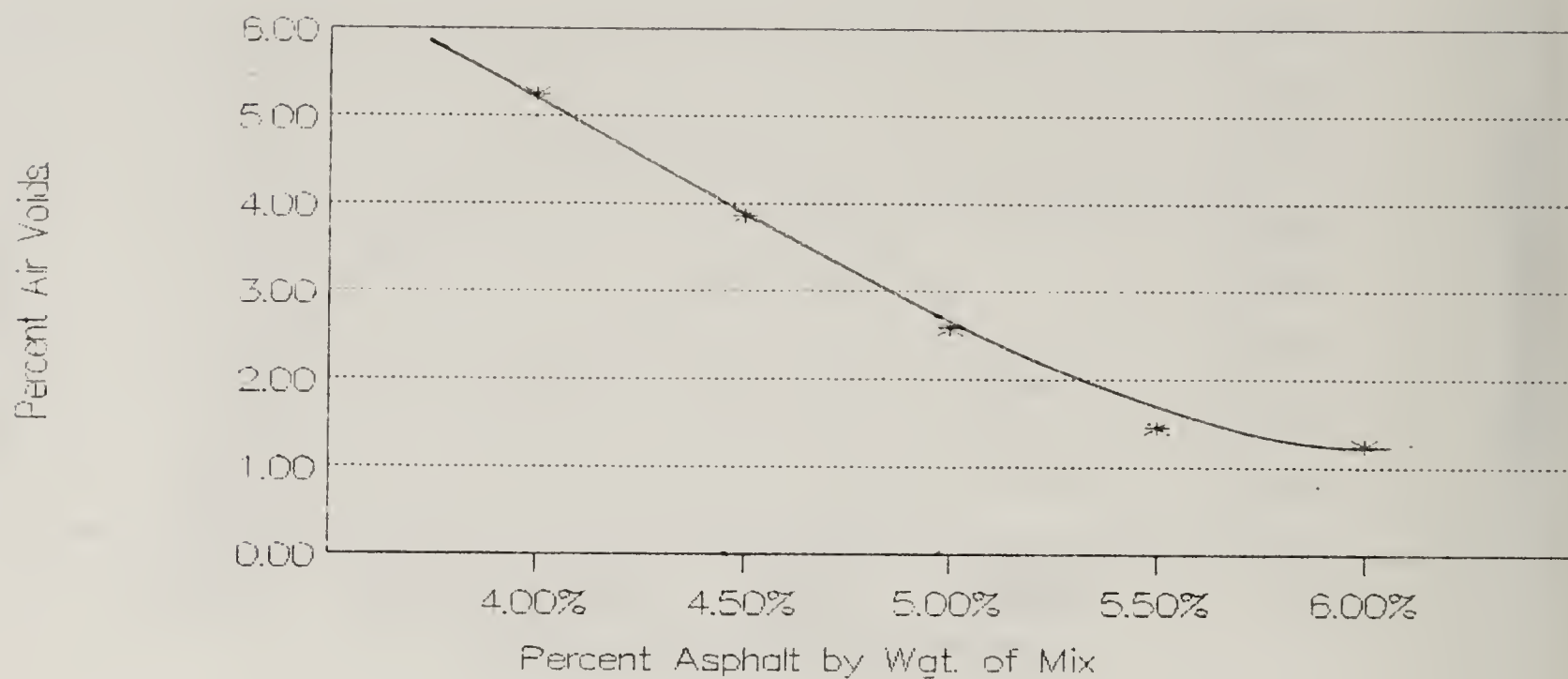
# Unmodified Conoco - I Gradation Agg.

112 Blows - Marshall Flow in 1/100 Inch



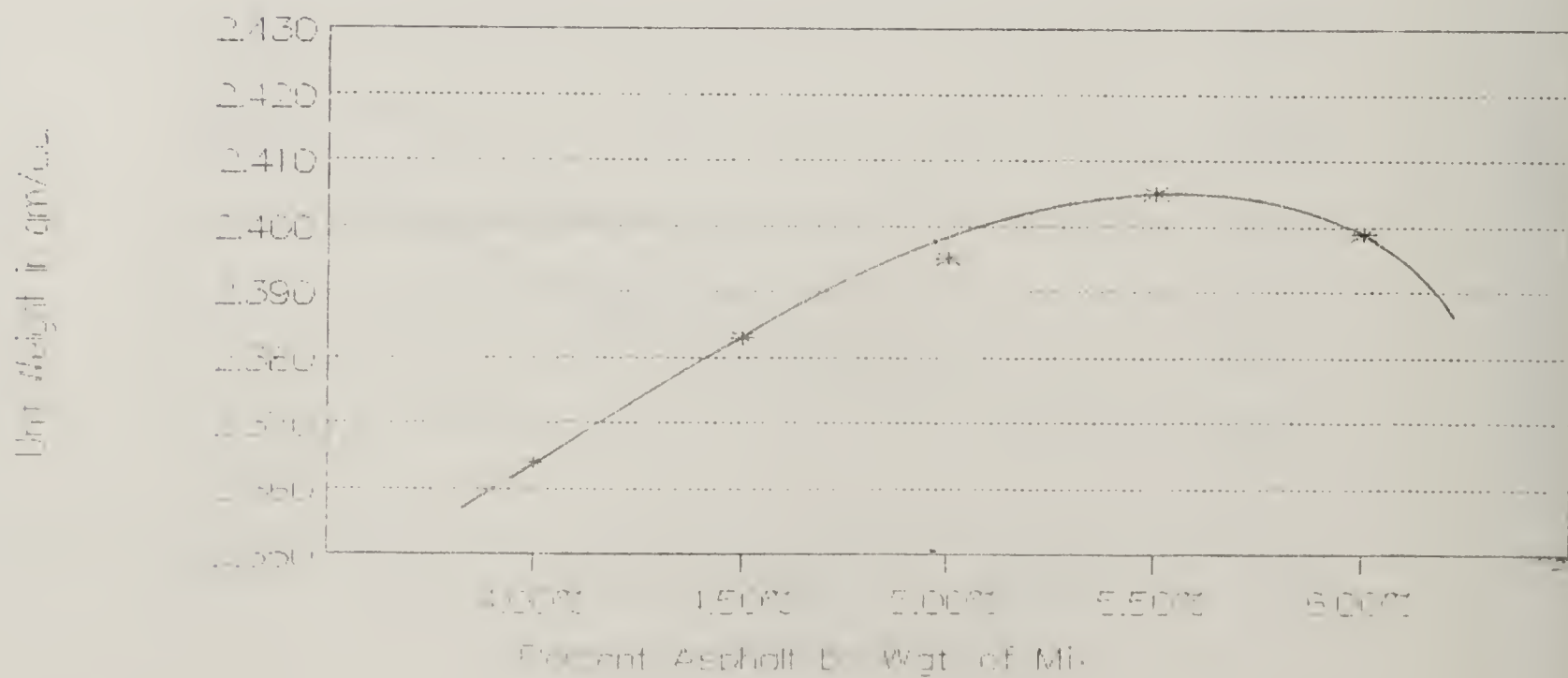
# Unmodified Conoco - I Gradation Agg.

112 Blows - Percent Air Voids.



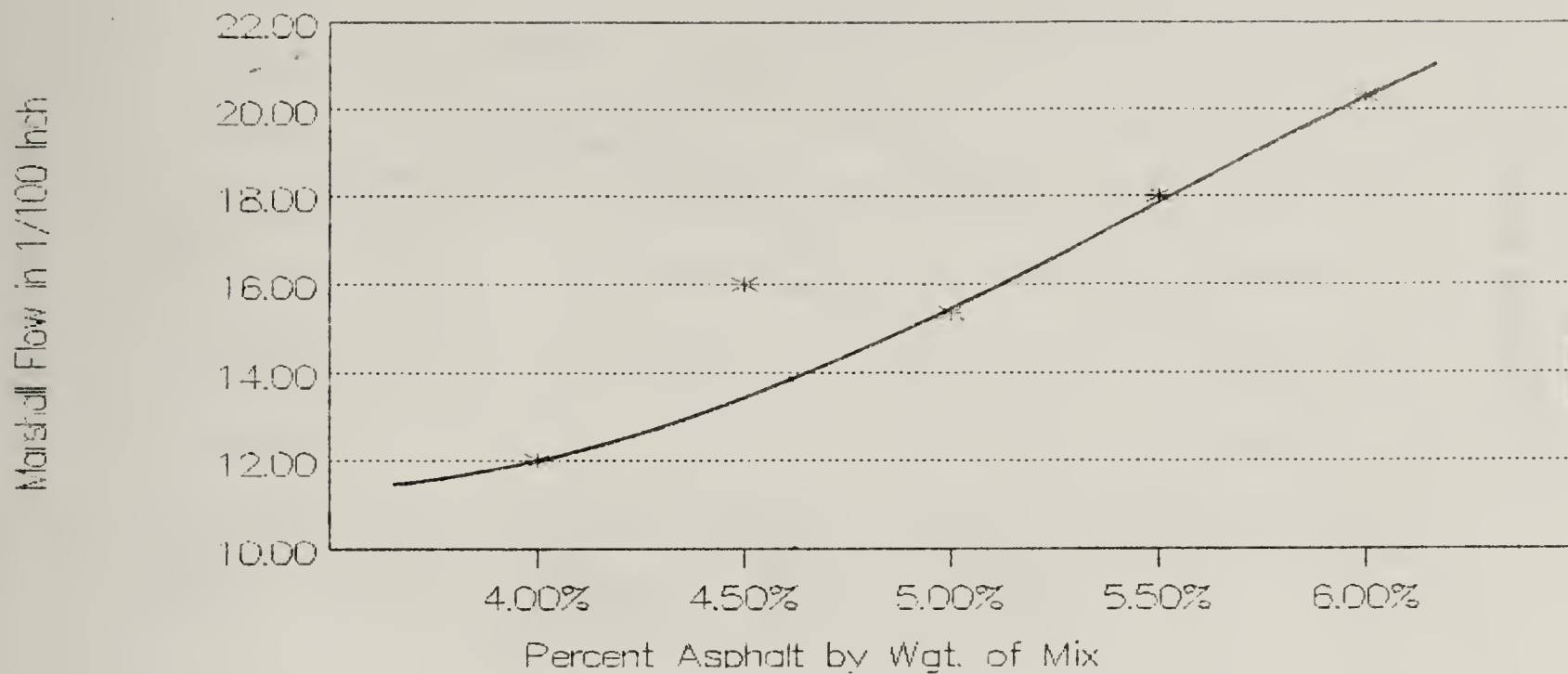
# Unmodified Conoco - I Gradation Agg.

112 Blows - Unit Weight in gm/c.c.



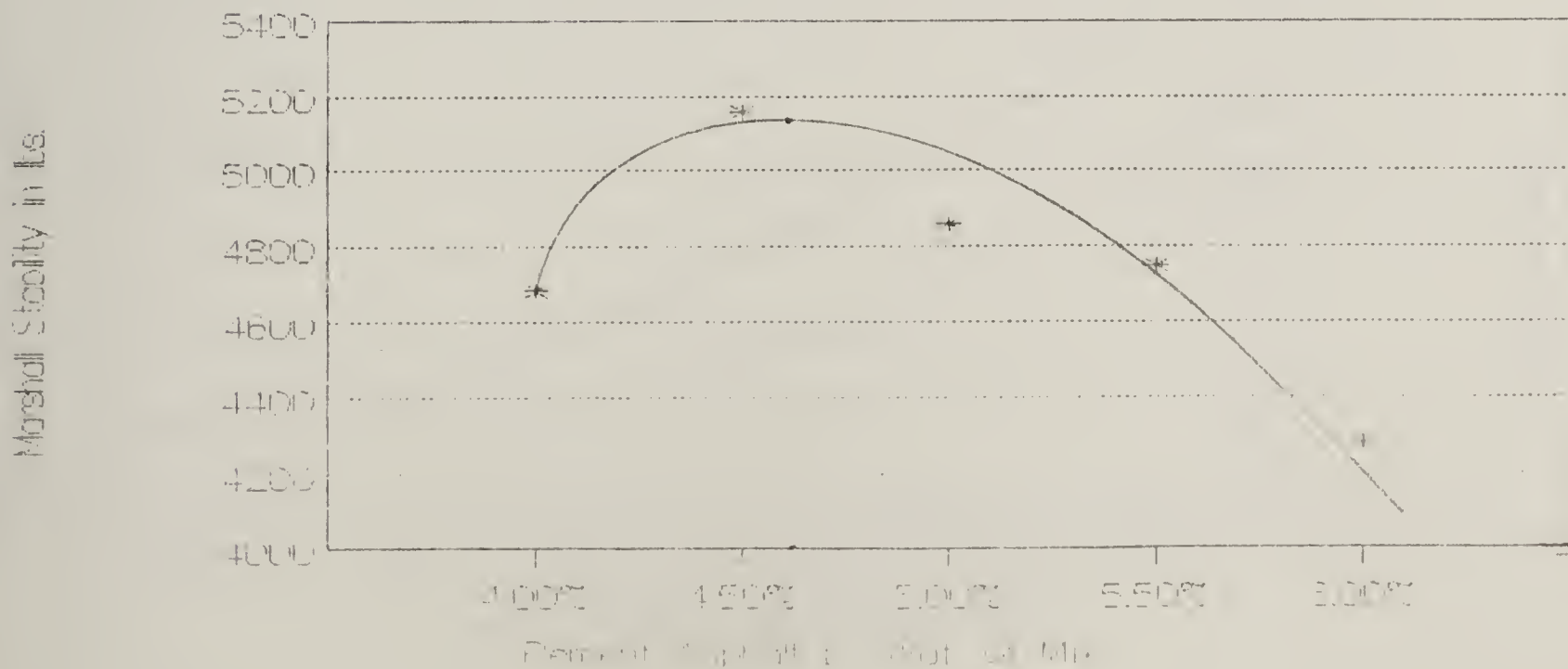
# Kraton Mod. Conoco - I Gradation Agg.

112 Blows - Marshall Flow in 1/100 Inch



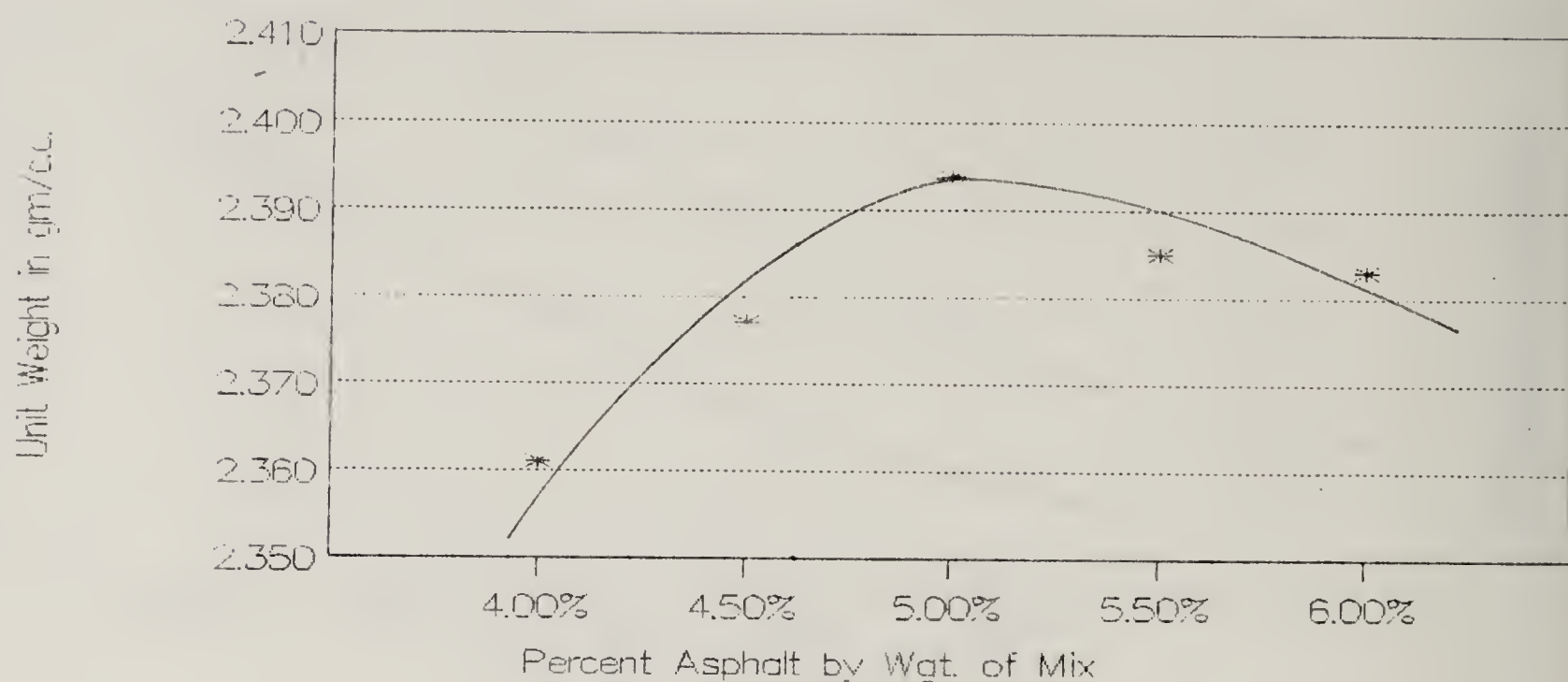
# Kraton Mod. Conoco - I Gradation Agg.

112 Blows - Marshall Stability in lbs.



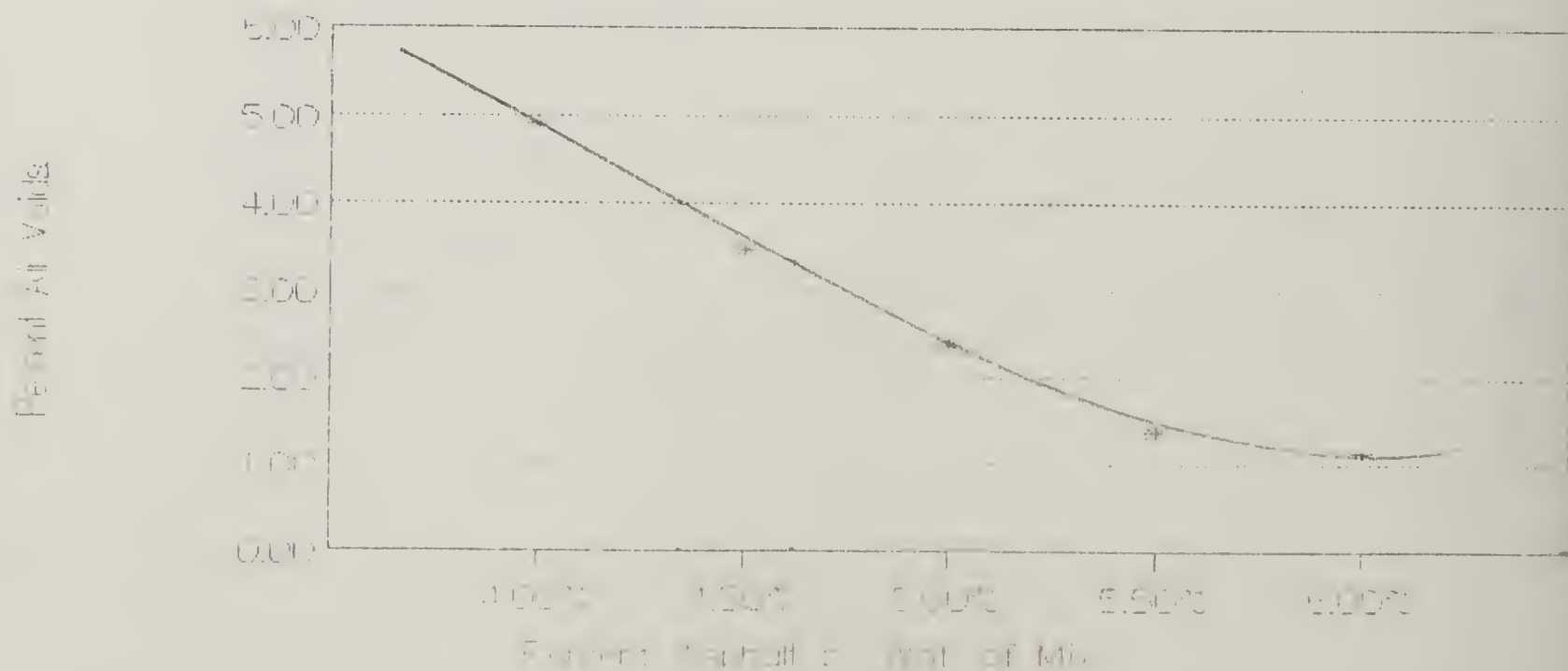
# Kraton Mod. Conoco - I Gradation Agg.

112 Blows - Unit Weight in gm/c.c.



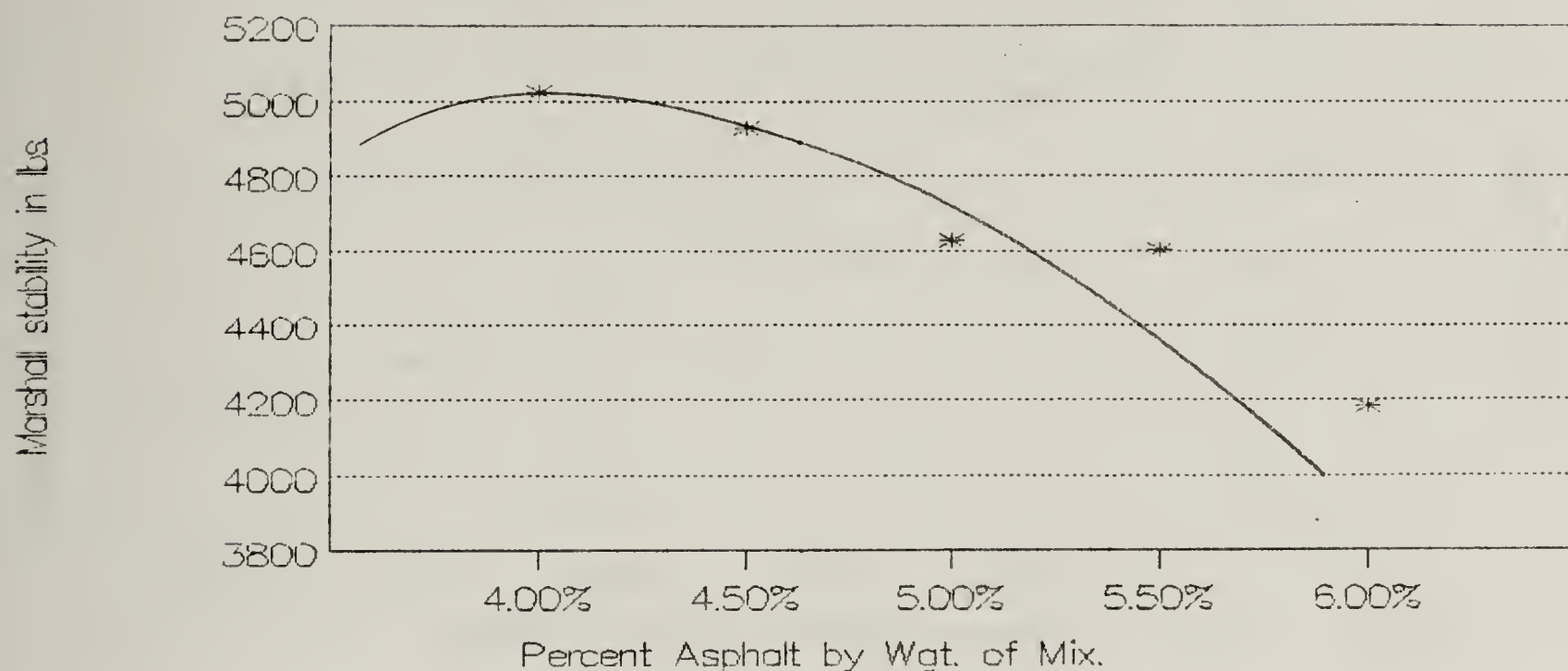
# Kraton Mod. Conoco - I Gradation Agg.

112 Blows - Percent Air Voids.



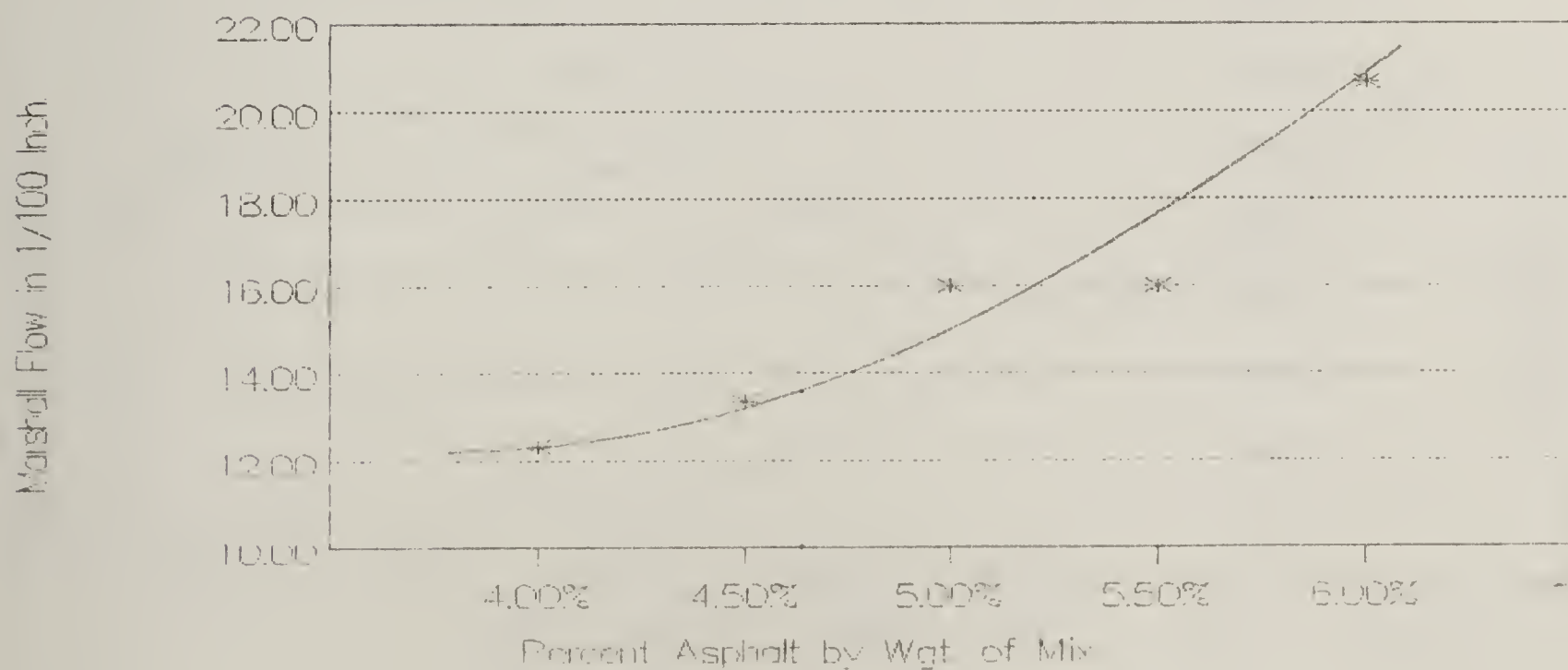
# Polybilt Mod. Conoco - I Gradation Agg.

## 112 Blow - Marshall Stability



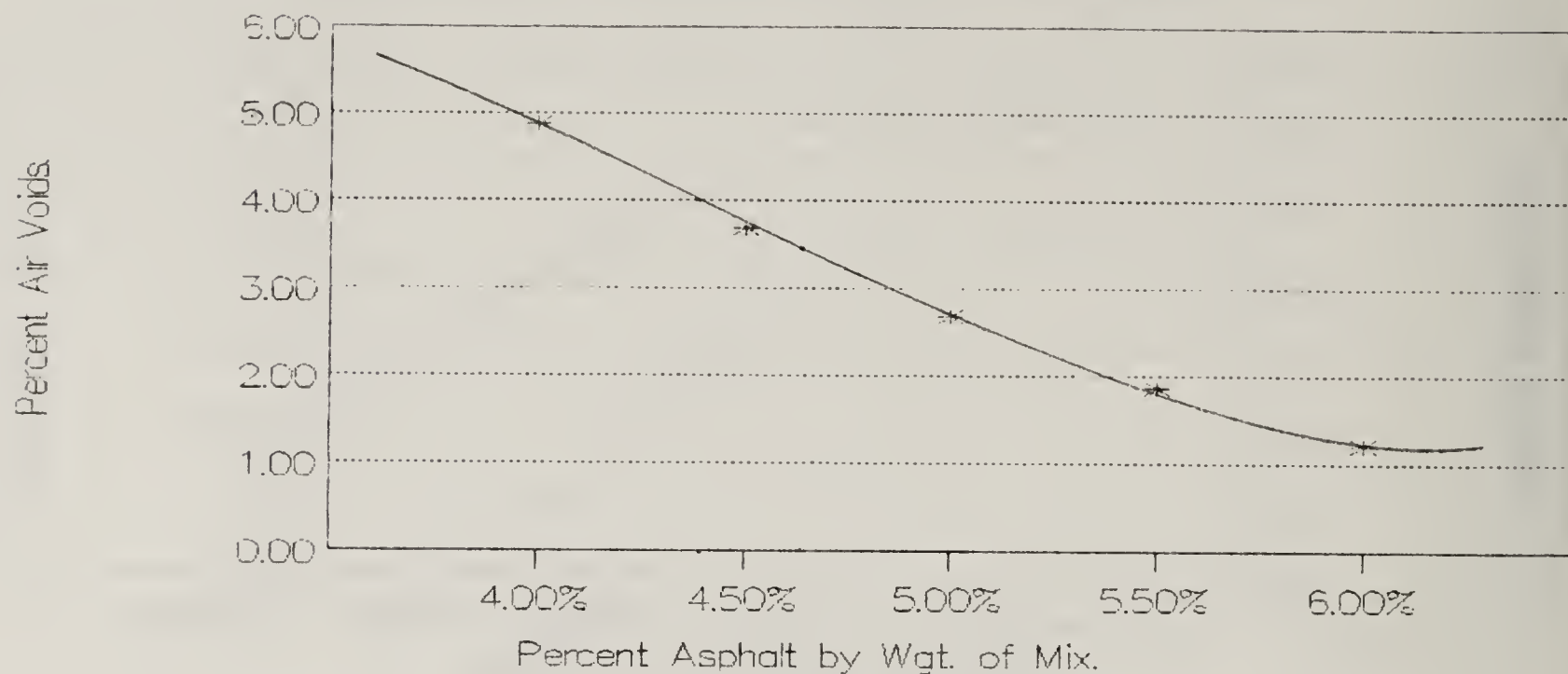
# Polybilt Mod. Conoco - I Gradation Agg.

## 112 Blow - Marshall Flow



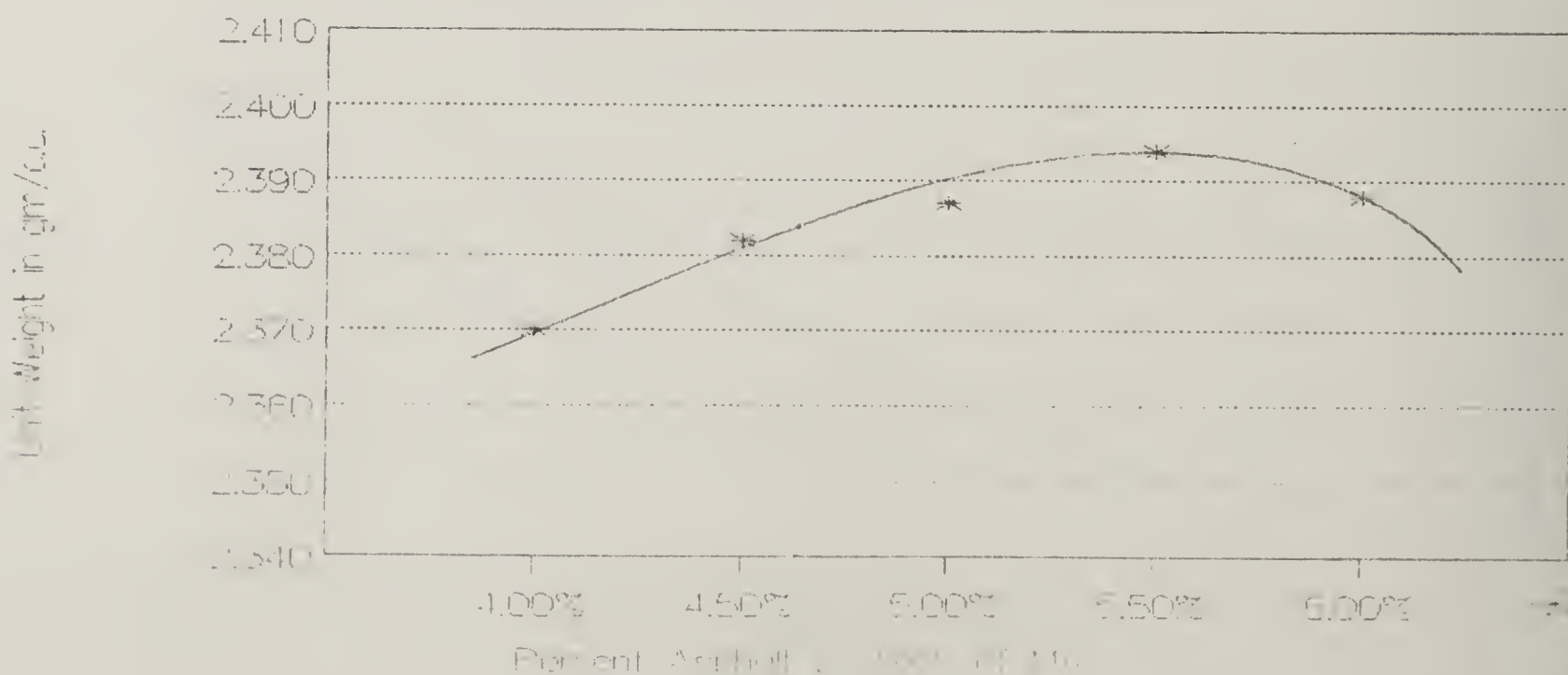
# Polybilt Mod. Conoco - I Gradation Agg.

112 Blow - Percent Air Voids.



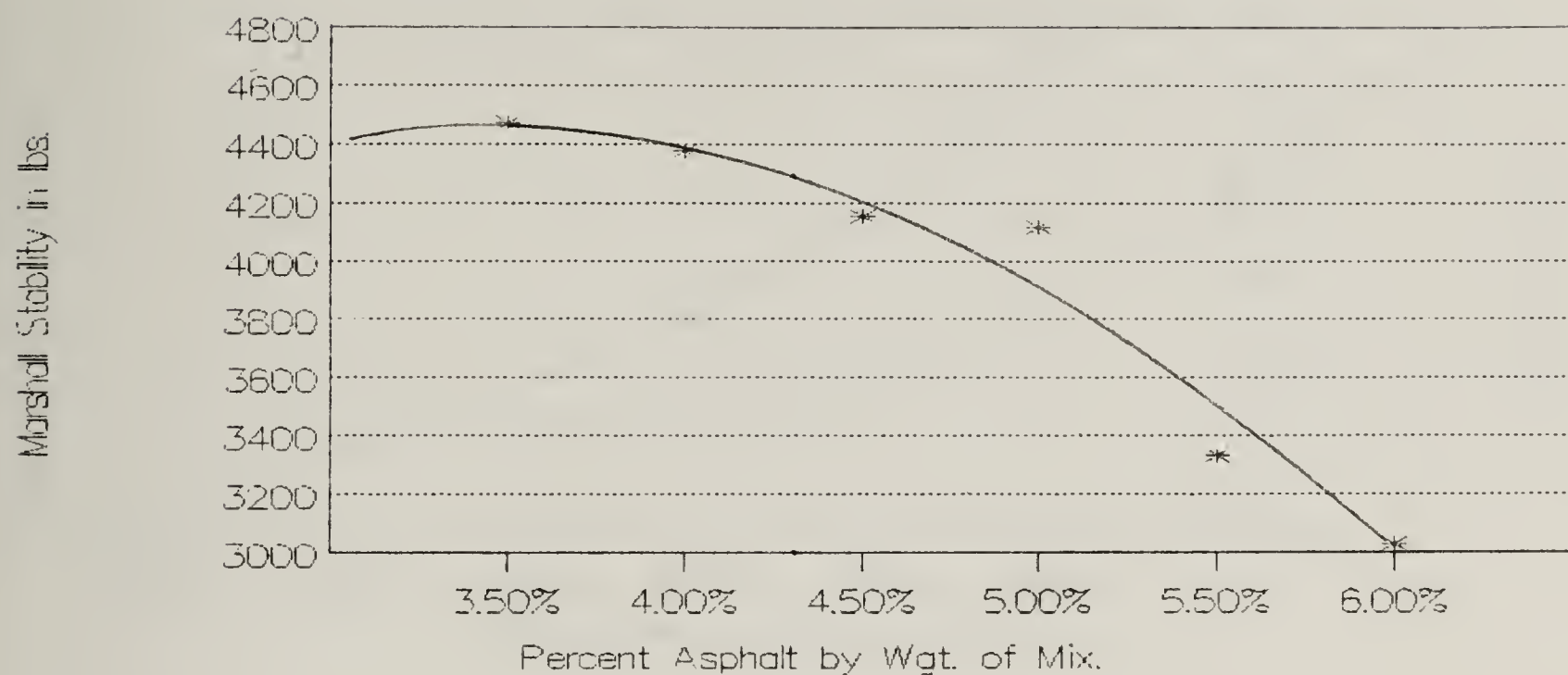
# Polybilt Mod. Conoco - I Gradation Agg.

112 Blow - Unit Weight in gm/c.c.



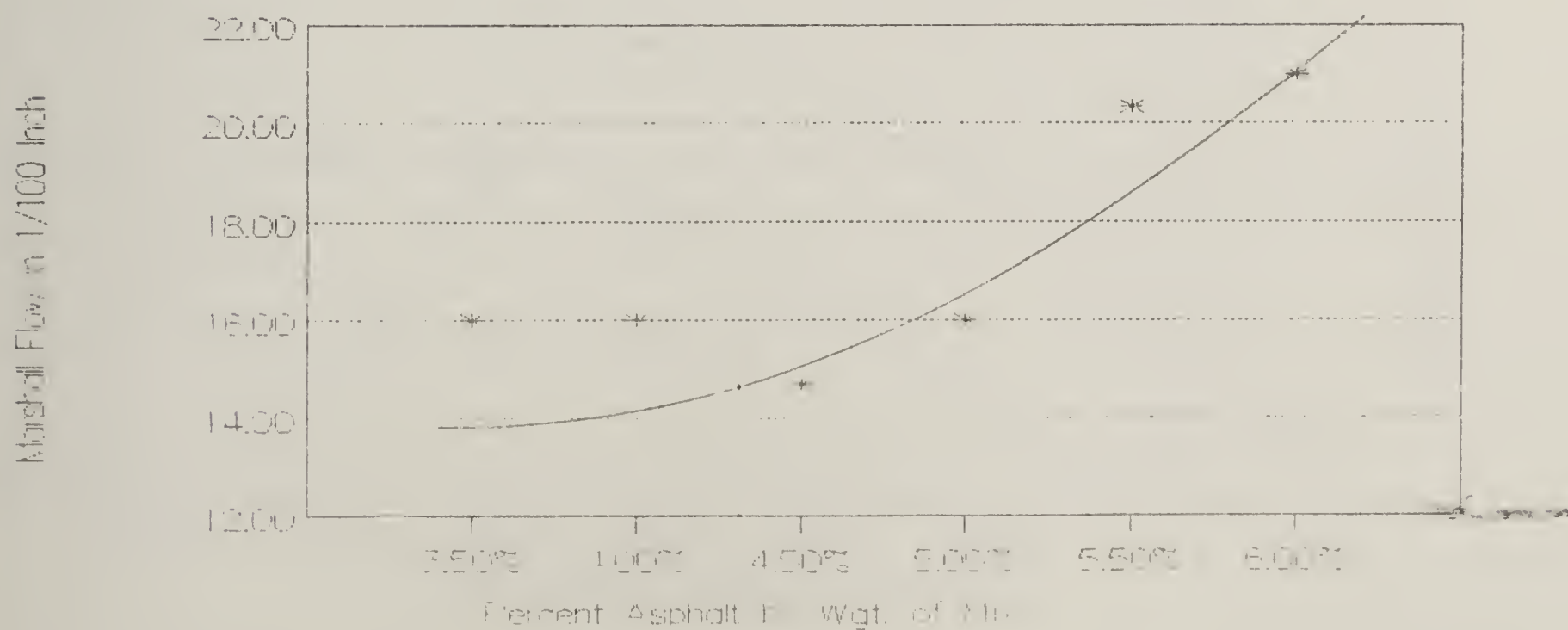
# Unmodified Conoco - I Gradation Agg.

## Mineral Filler - Marshall Stability.



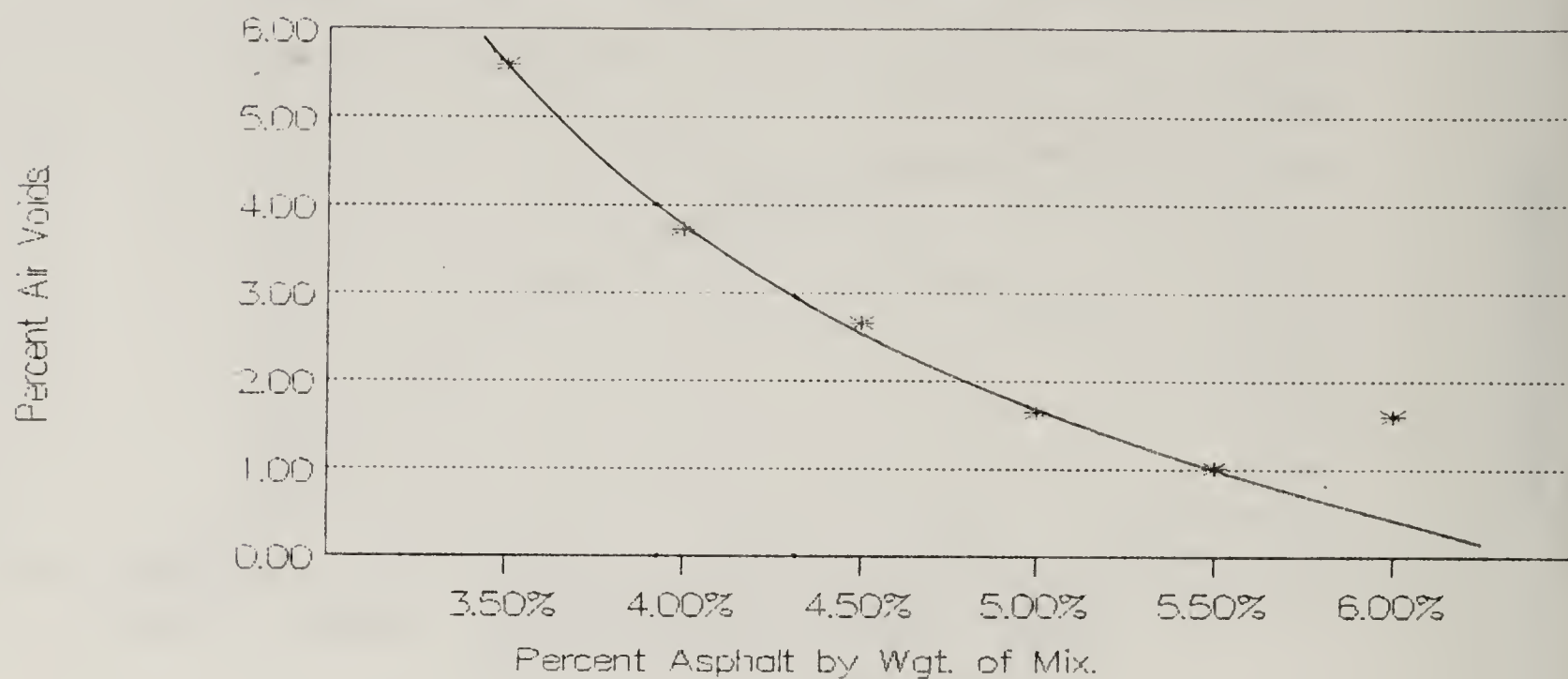
# Unmodified Conoco - I Gradation Agg.

## Mineral Filler - Marshall Flow 1/100 in



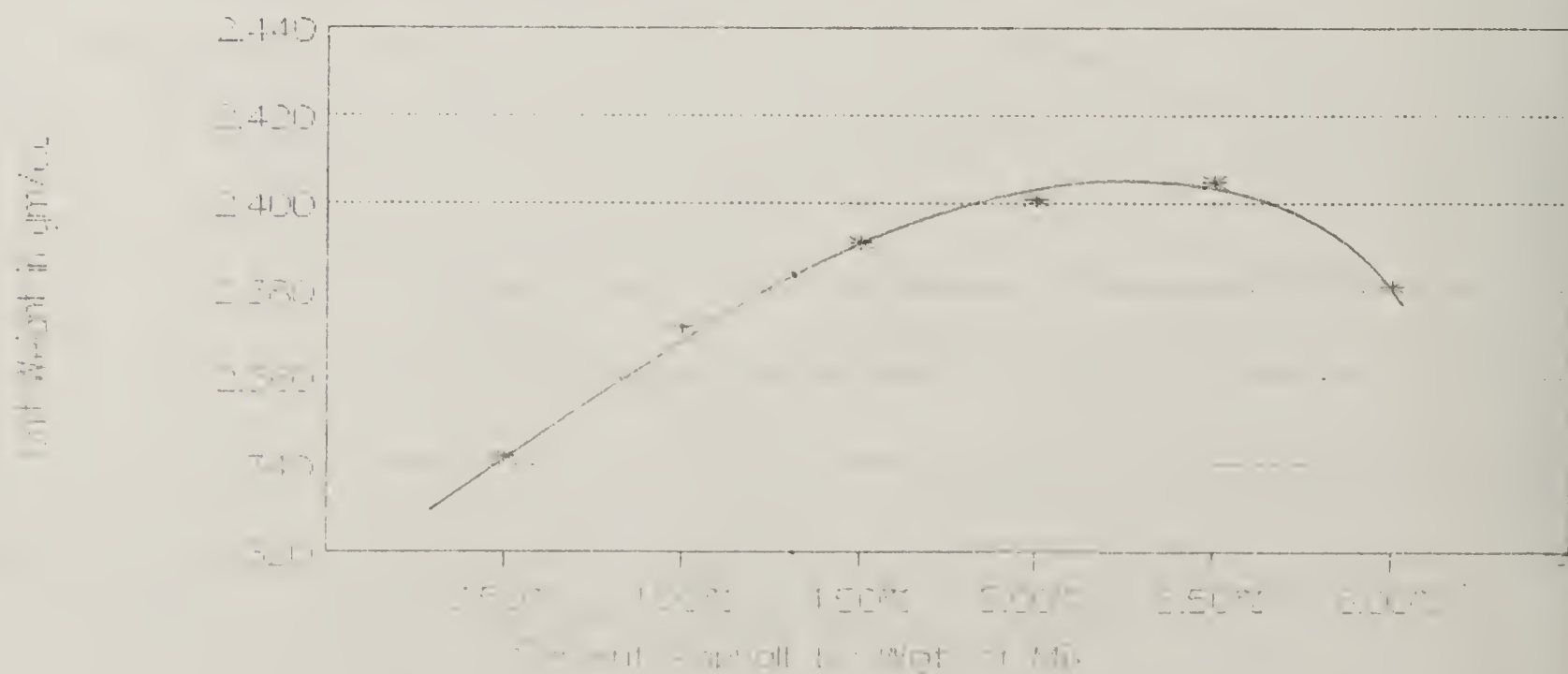
# Unmodified Conoco - I Gradation Agg.

## Mineral Filler - Percent Air Voids.



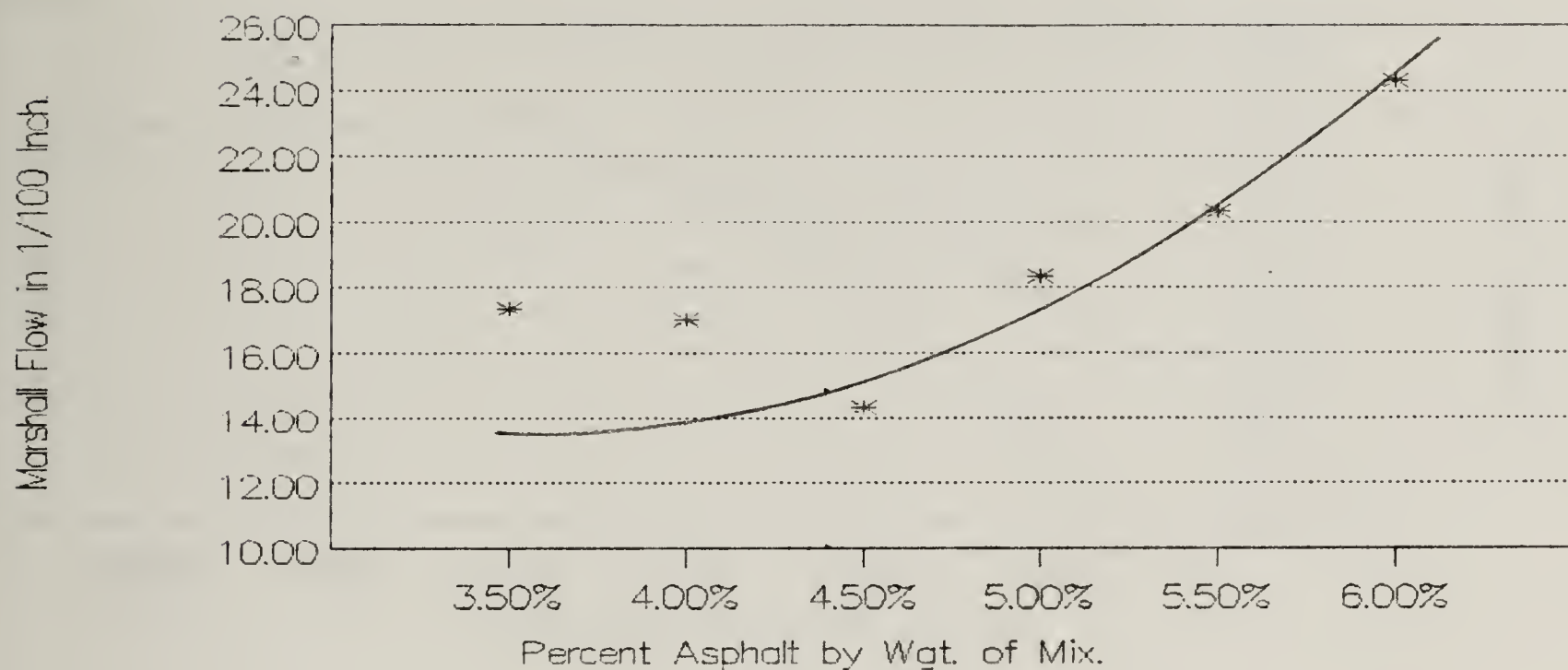
# Unmodified Conoco - I Gradation Agg.

## Mineral Filler - Unit Weight in gm/c.c.



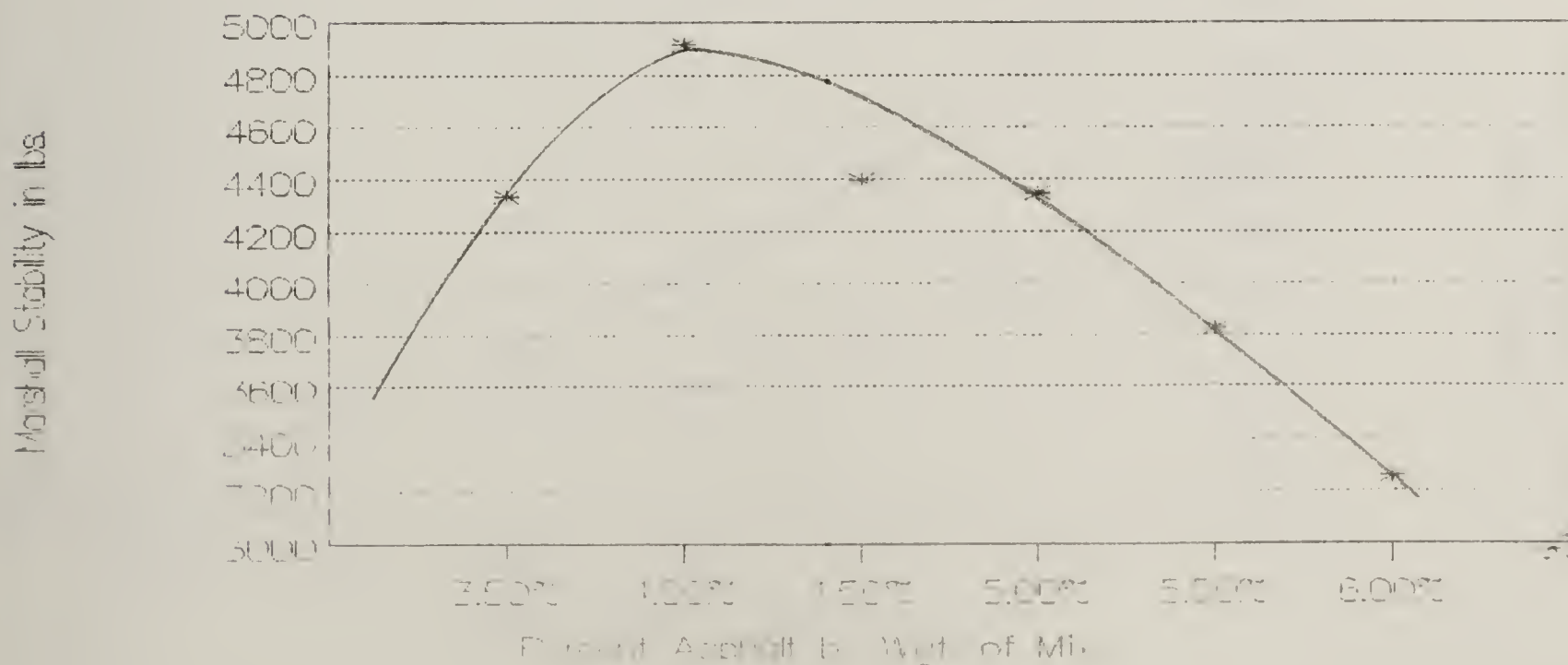
# Kraton Mod. Conoco — I Gradation Agg.

## Miller Filler — Marshall Flow.



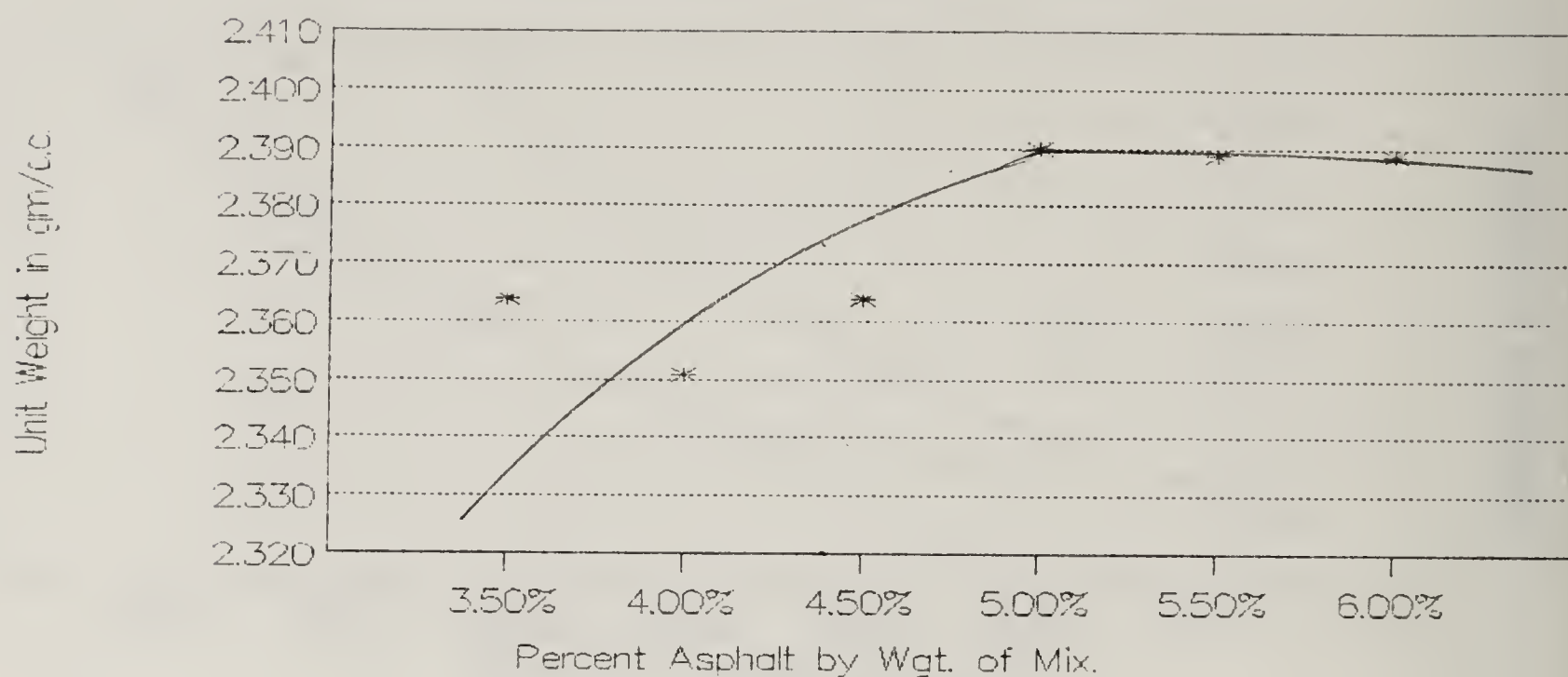
# Kraton Mod. Conoco — I Gradation Agg.

## Miller Filler — Marshall Stability.



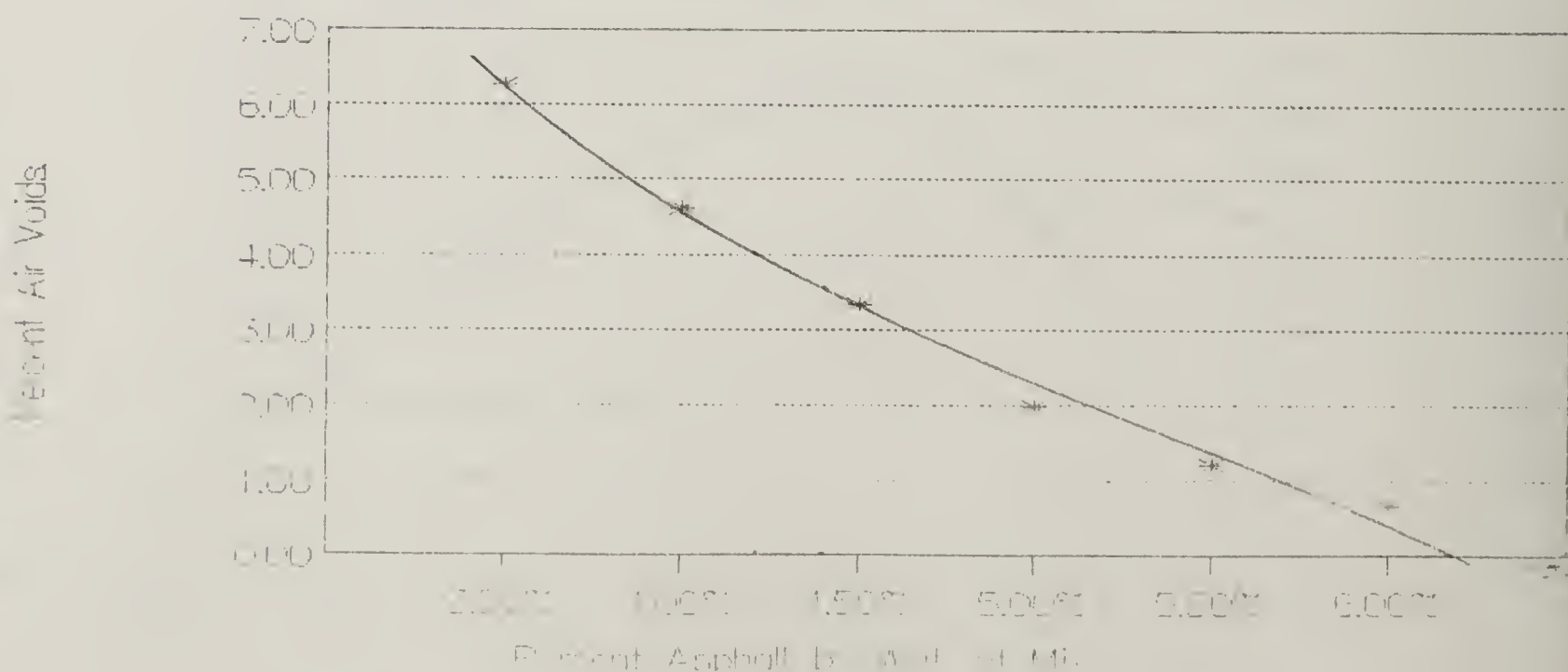
# Kraton Mod. Conoco — I Gradation Agg.

Miller Filler — Unit Weight in gm/c.c.



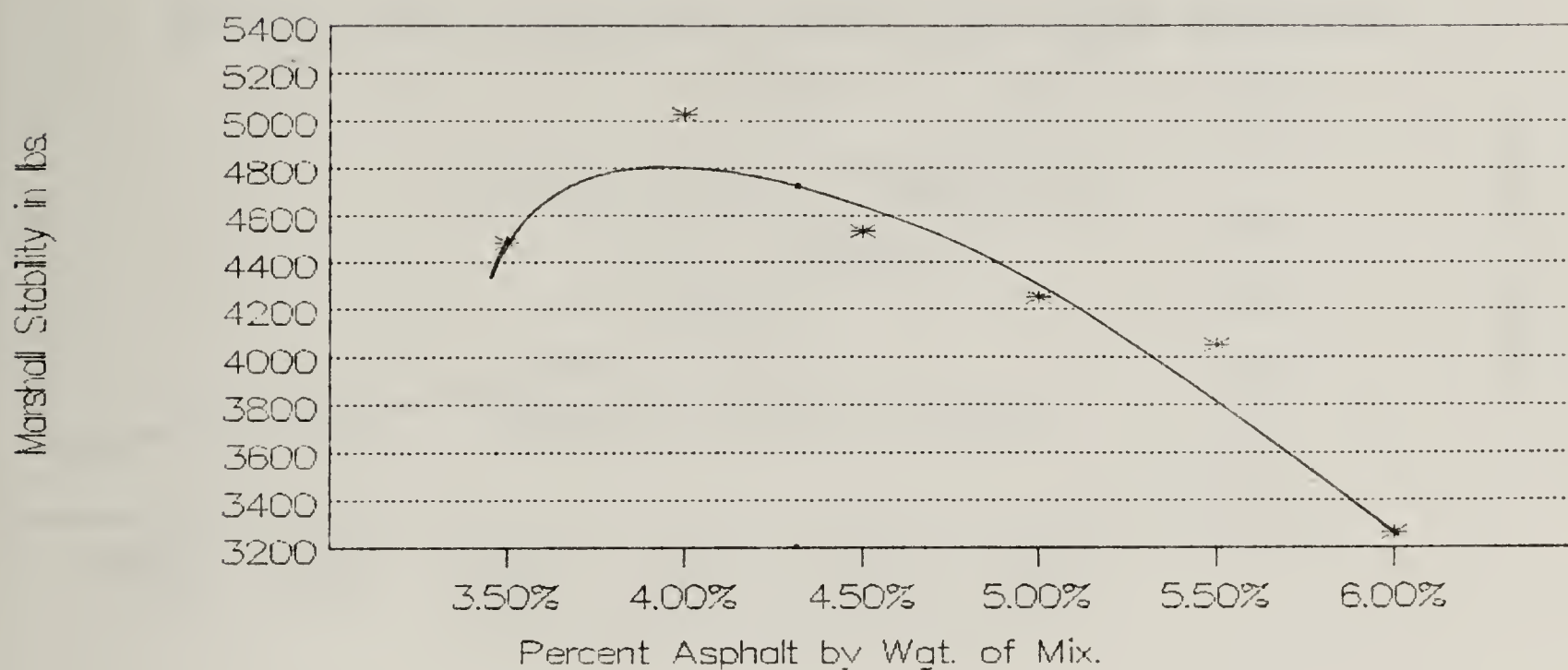
# Kraton Mod. Conoco — I Gradation Agg.

Miller Filler — Percent Air Voids.



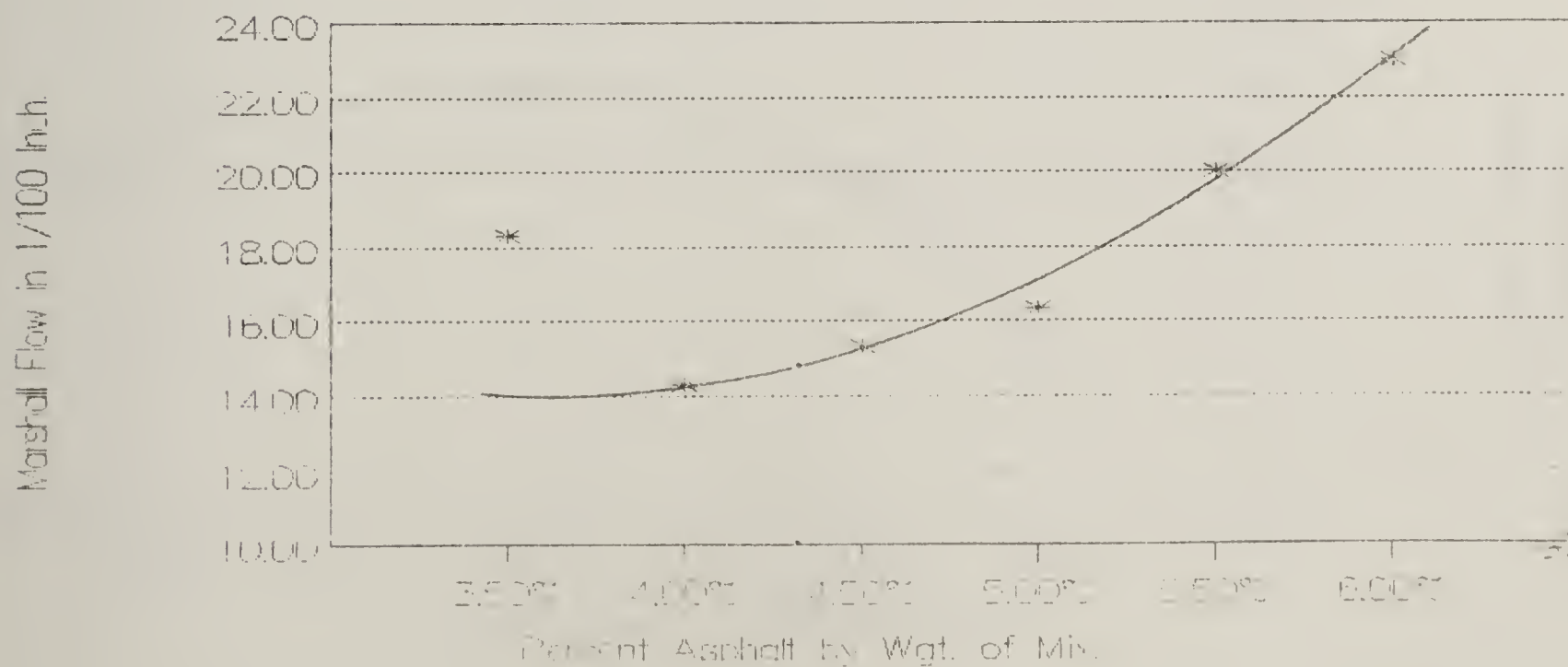
# Polybilt Mod. Conoco - I Gradation Agg.

## Miller Filler - Marshall Stability.



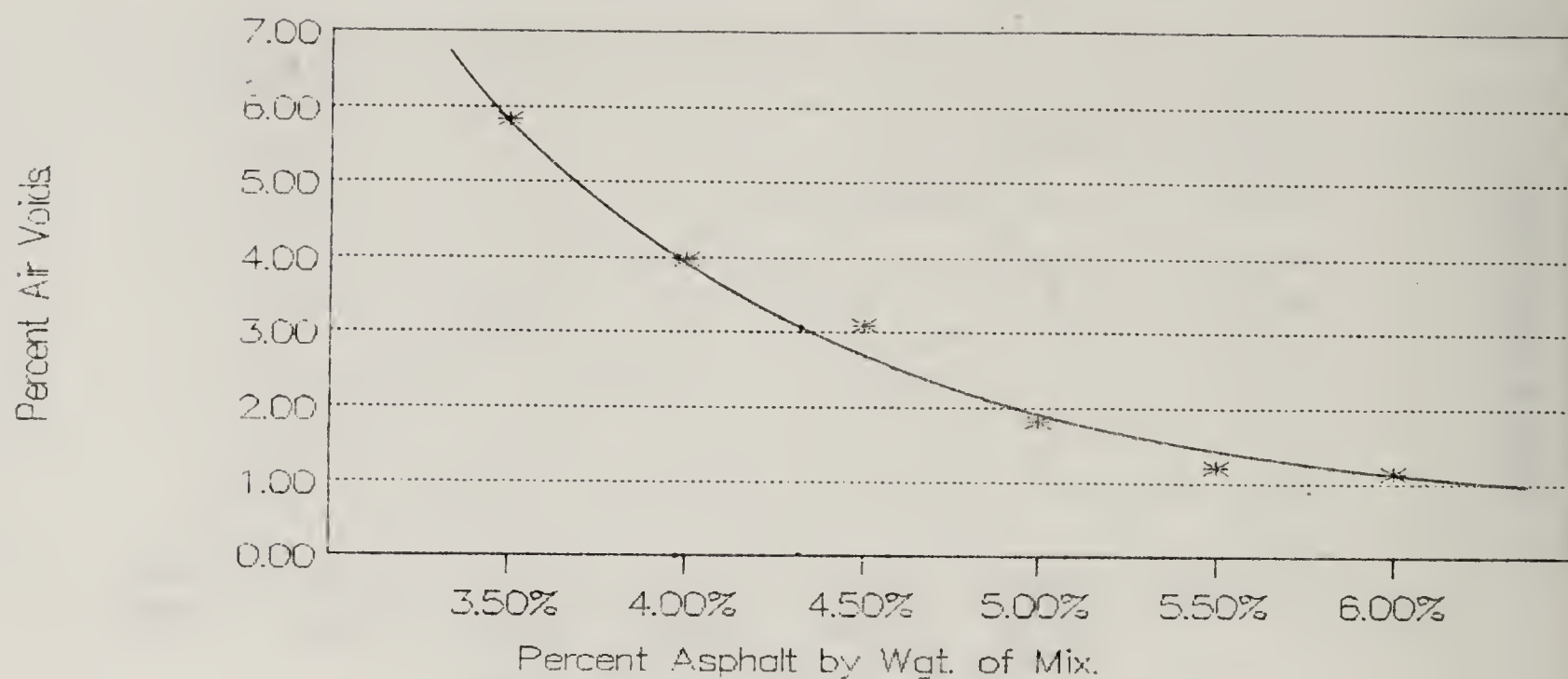
# Polybilt Mod. Conoco - I Gradation Agg.

## Miller Filler - Marshall Flow.



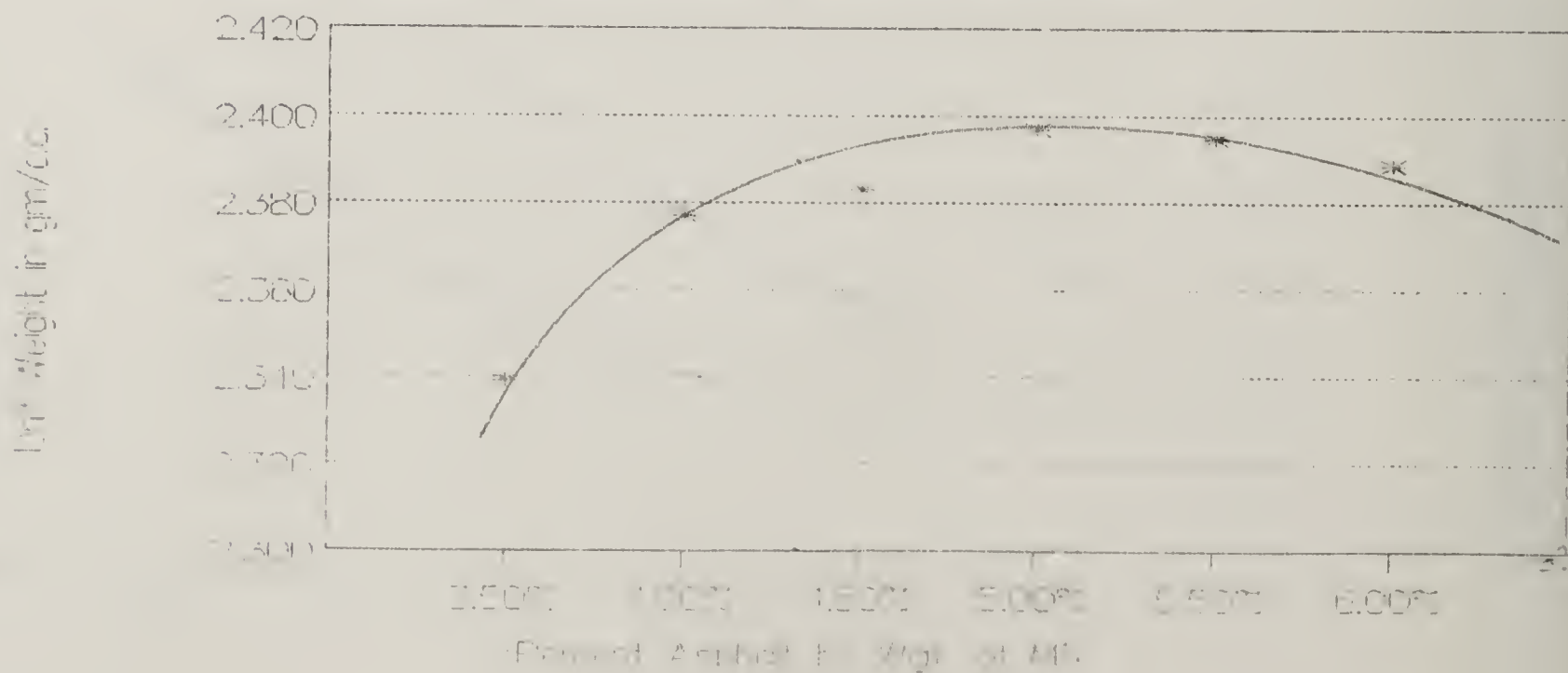
# Polybilt Mod. Conoco - I Gradation Agg.

## Miller Filler - Percent Air Voids.



# Polybilt Mod. Conoco - I Gradation Agg.

## Miller Filler - Unit Weight in gm/c.c.



Appendix C

Marshall Test Properties Curves for 6-inch Specimens

with

Second Gradation Aggregates

75 and 112 Blows

and

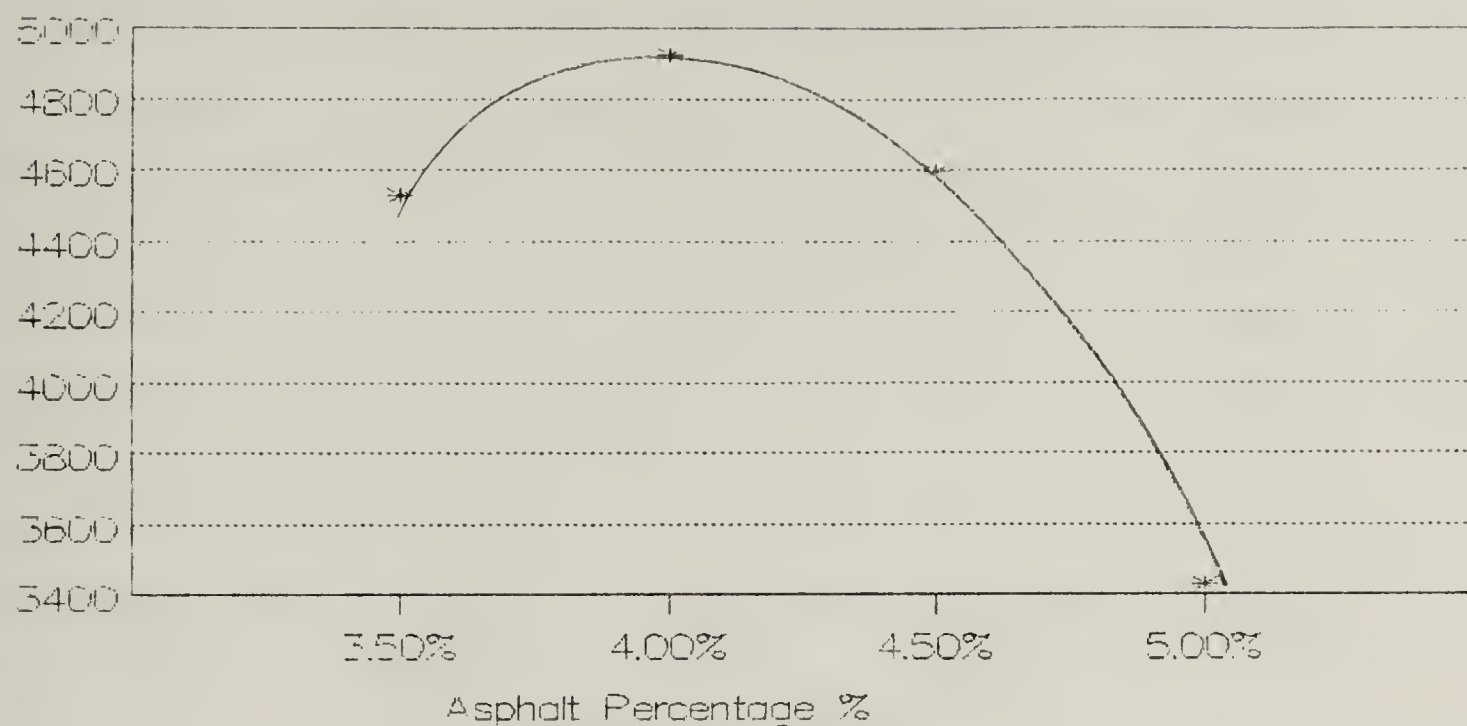
Mineral Filler 75 Blows

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# Unmodified Cenex - II Gradation Agg.

Marshall Stability in Lbs. (75 Blows).

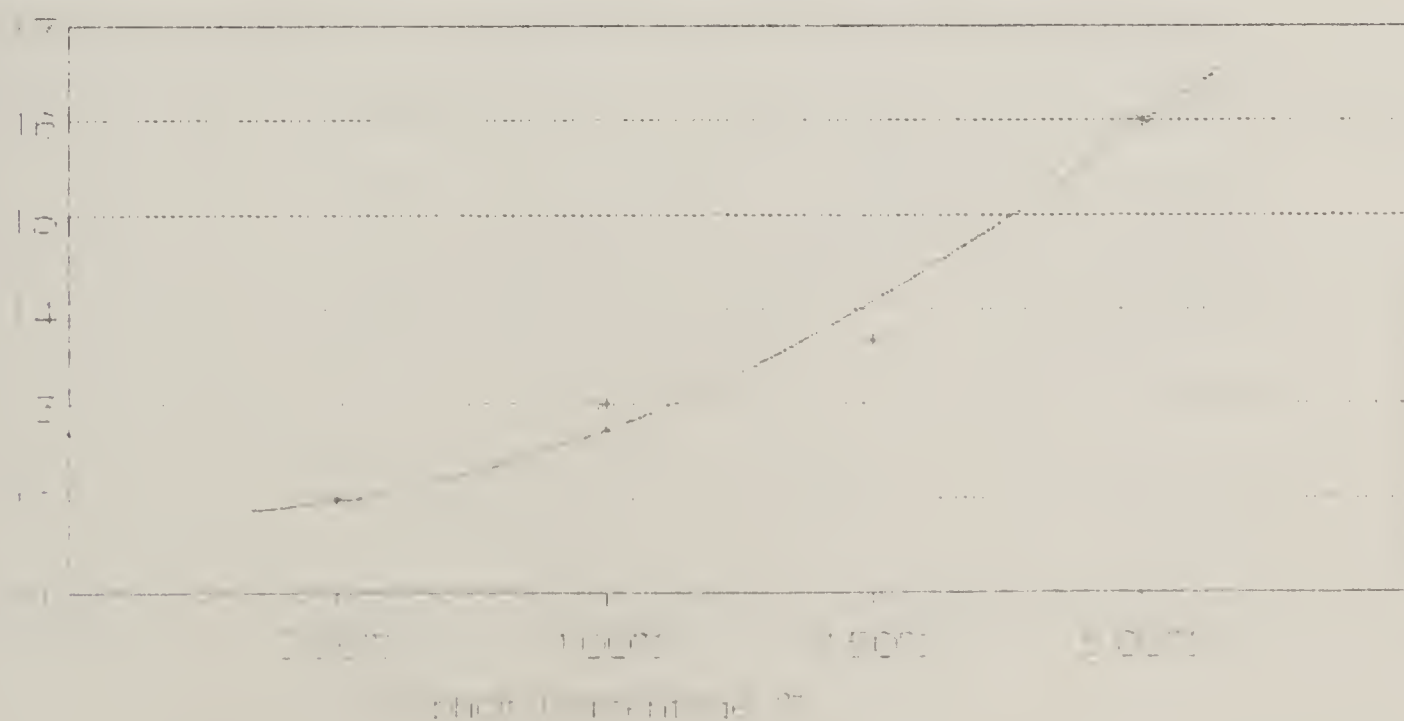
Marshall Stability in Lbs.



# Unmodified Cenex - II Gradation Agg.

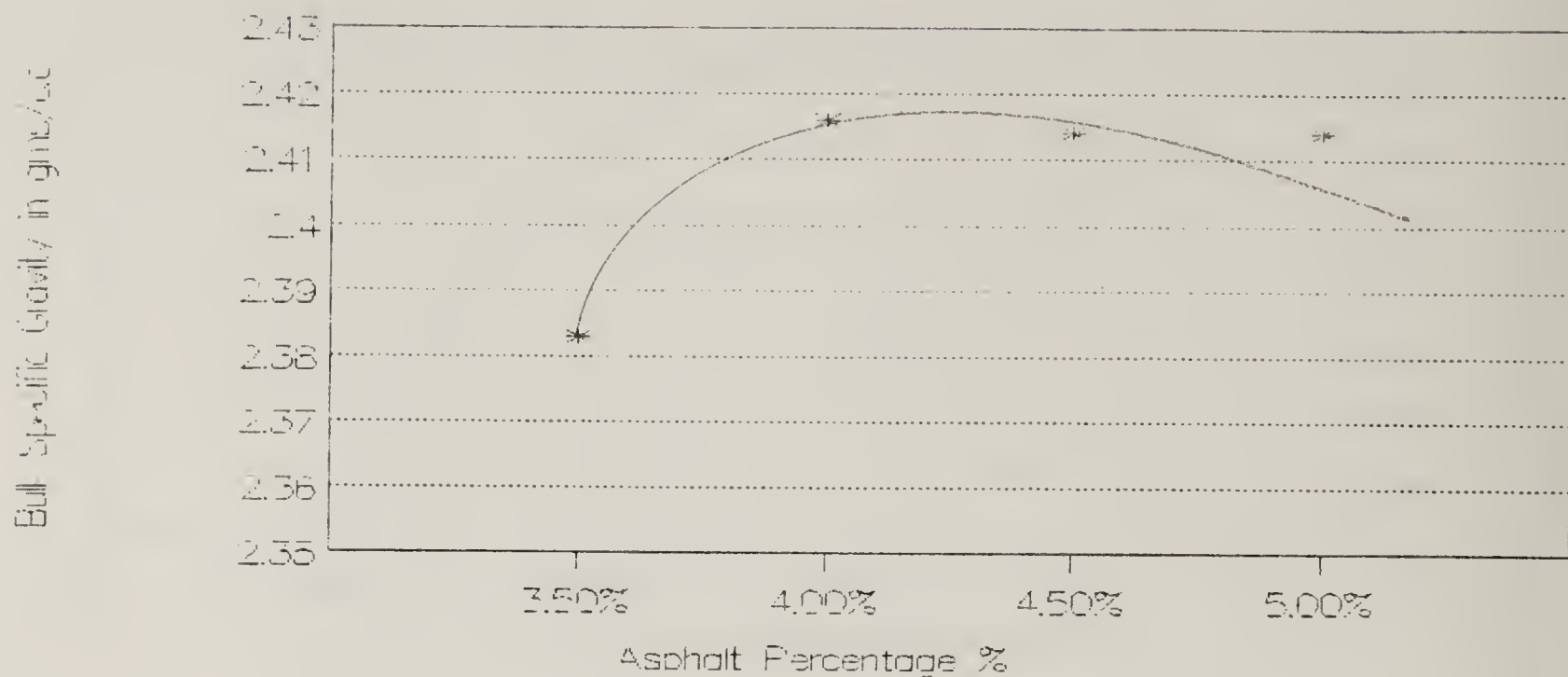
Marshall Flow in 1/100 Inch (75 Blows).

Marshall Flow in 1/100 Inch



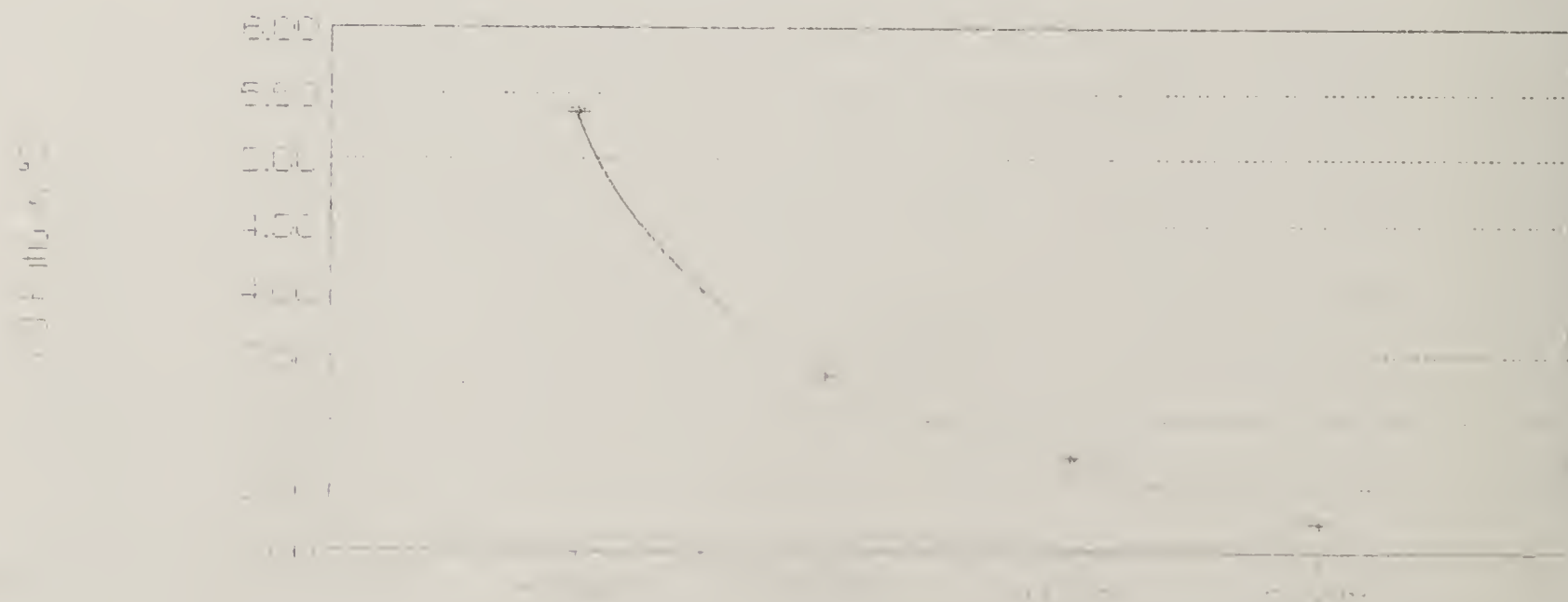
# Unmodified Cenex - II Gradation Agg.

Bulk Specific Gravity (75 Blows).



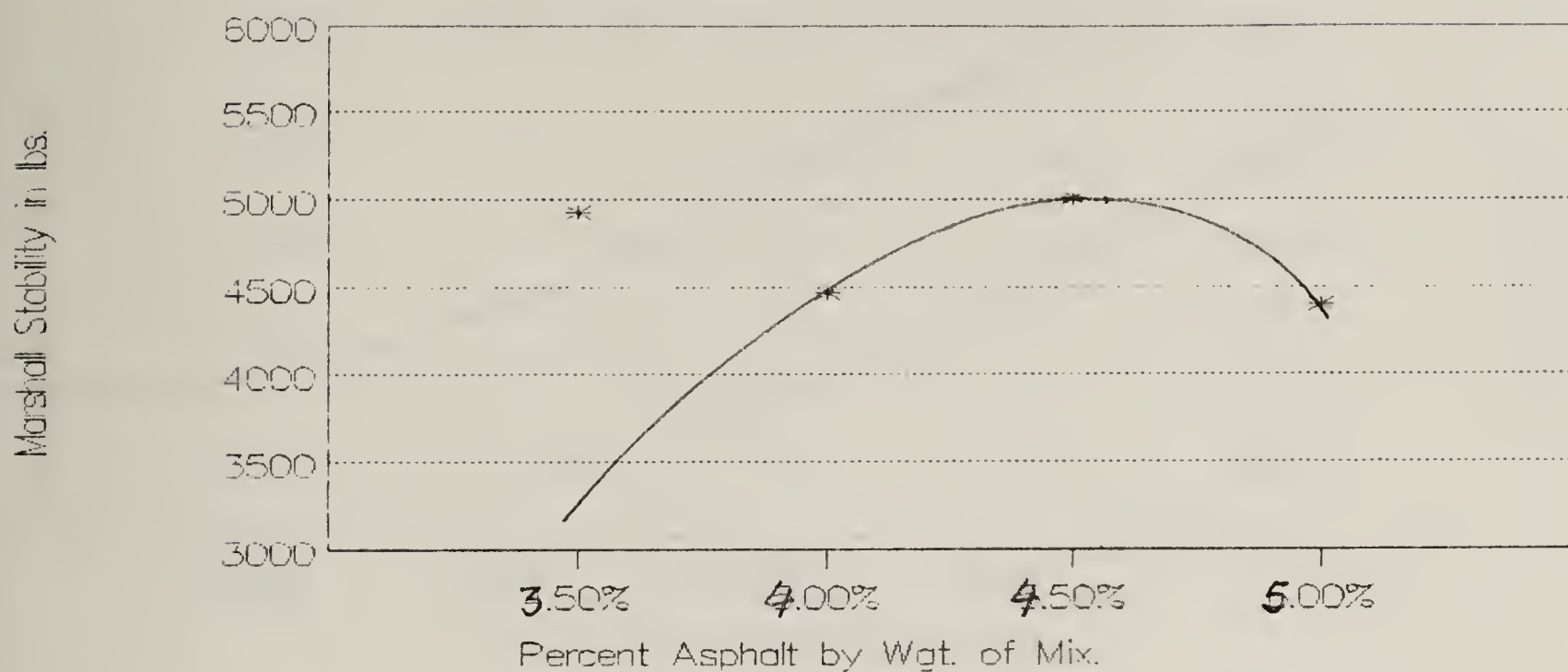
# Unmodified Cenex - II Gradation Agg.

Air Void Ratio in % (75 Blows).



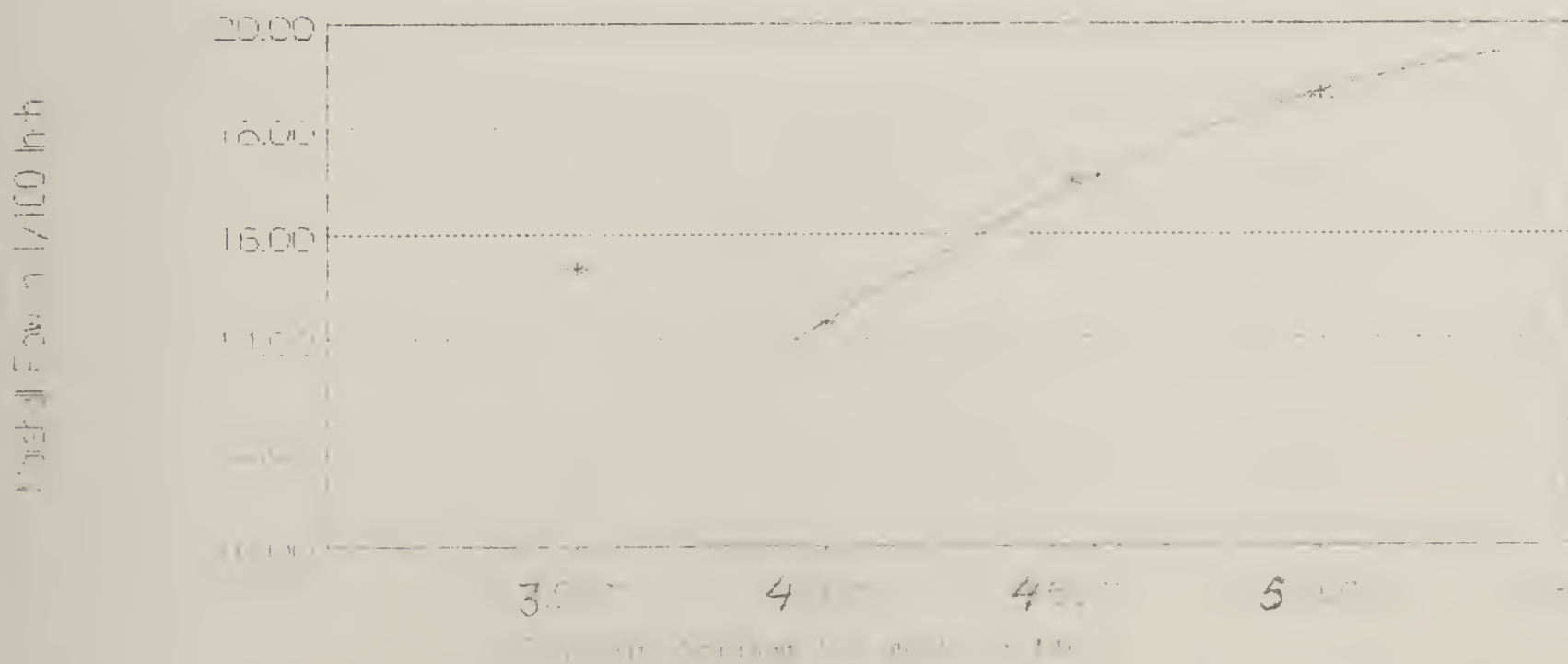
# Kraton Mod. Cenex - II Gradation Agg.

75 Blows - Marshall Stability.



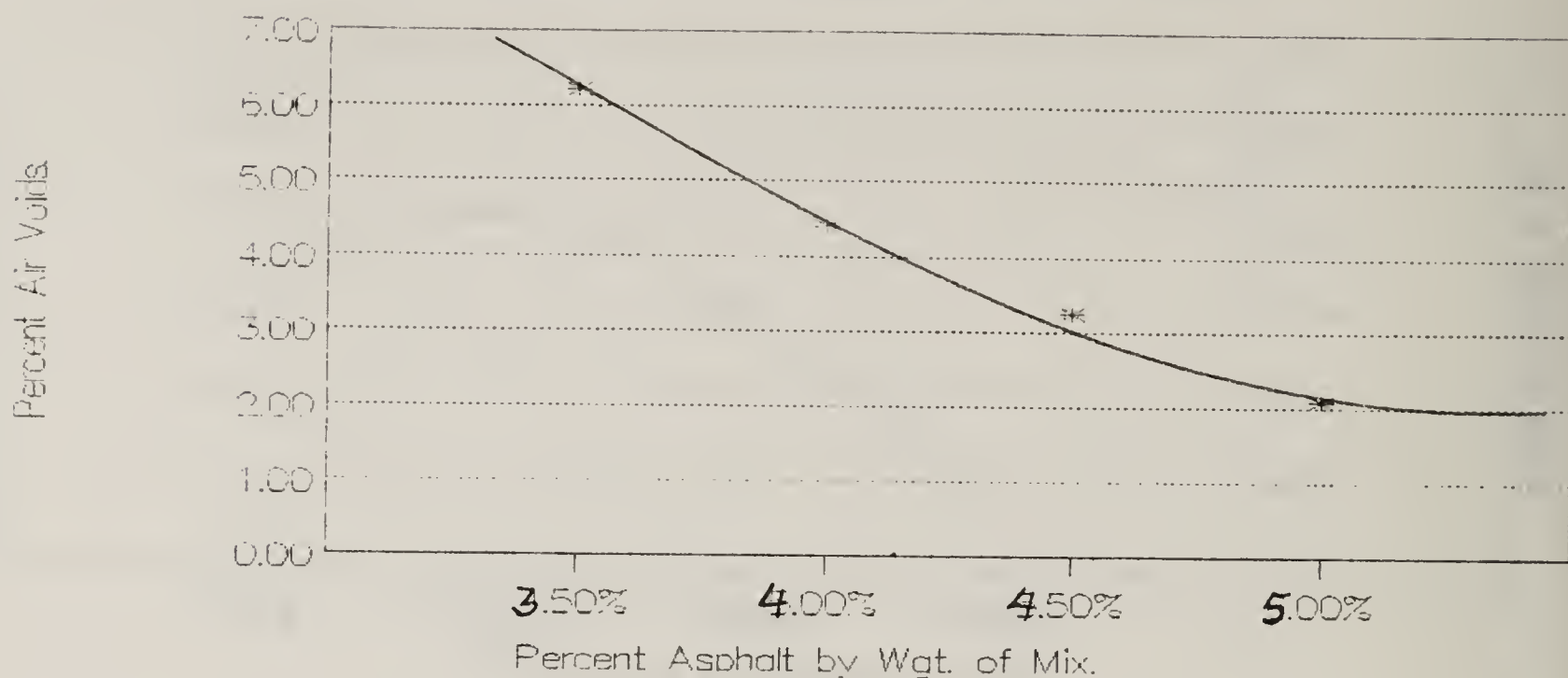
# Kraton Mod. Cenex - II Gradation Agg.

75 Blows - Marshall Flow in 1/100 inch.



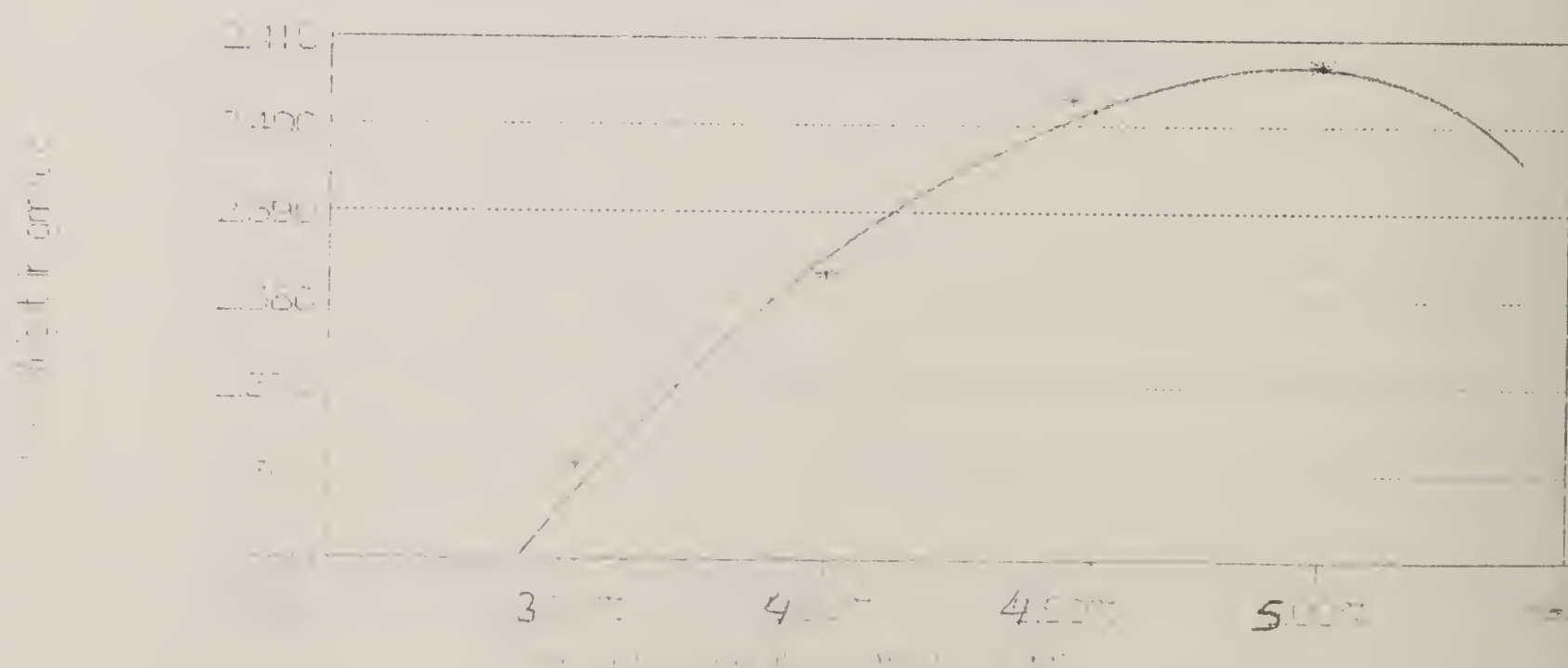
# Kraton Mod. Cenex — II Gradation Agg.

75 Blows — Percent Air Voids.



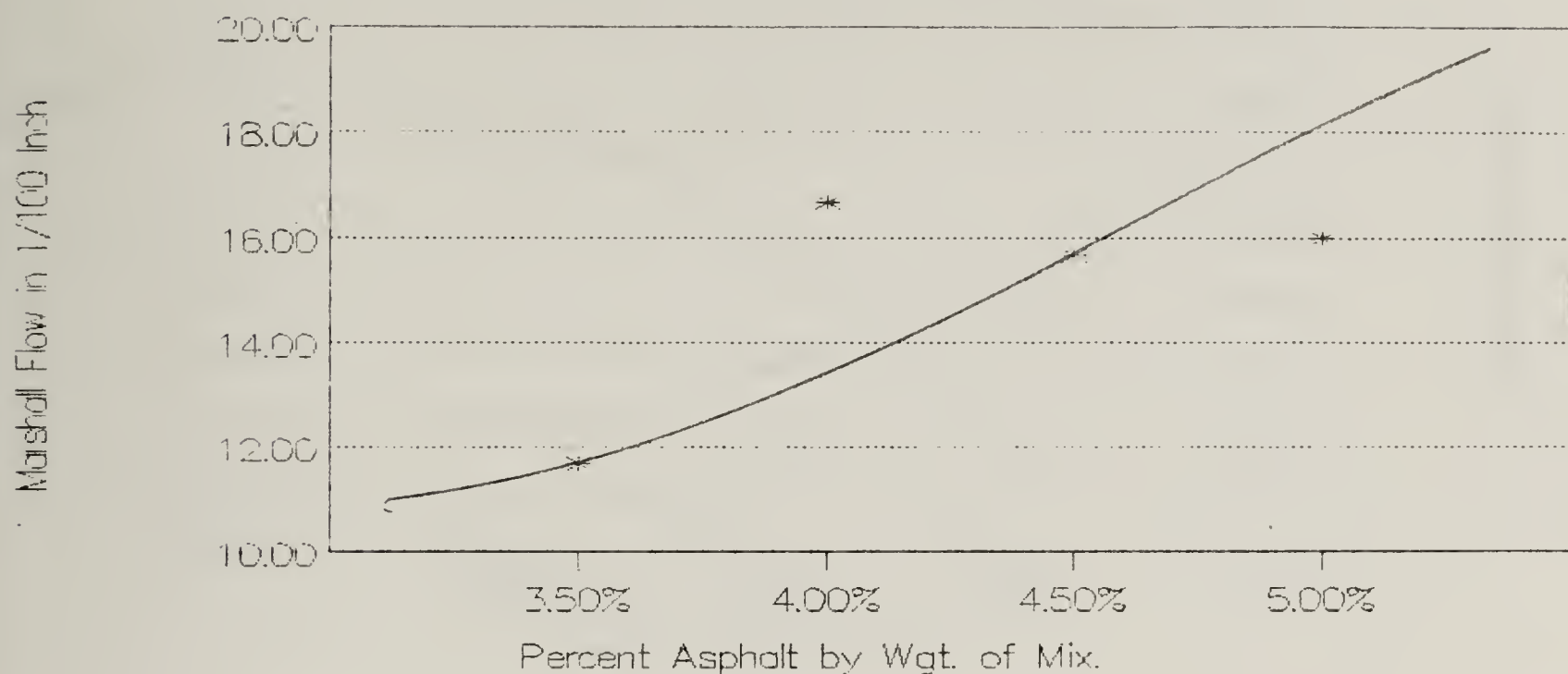
# Kraton Mod. Cenex — II Gradation Agg.

75 Blows — Unit Weight in gm/c.c.



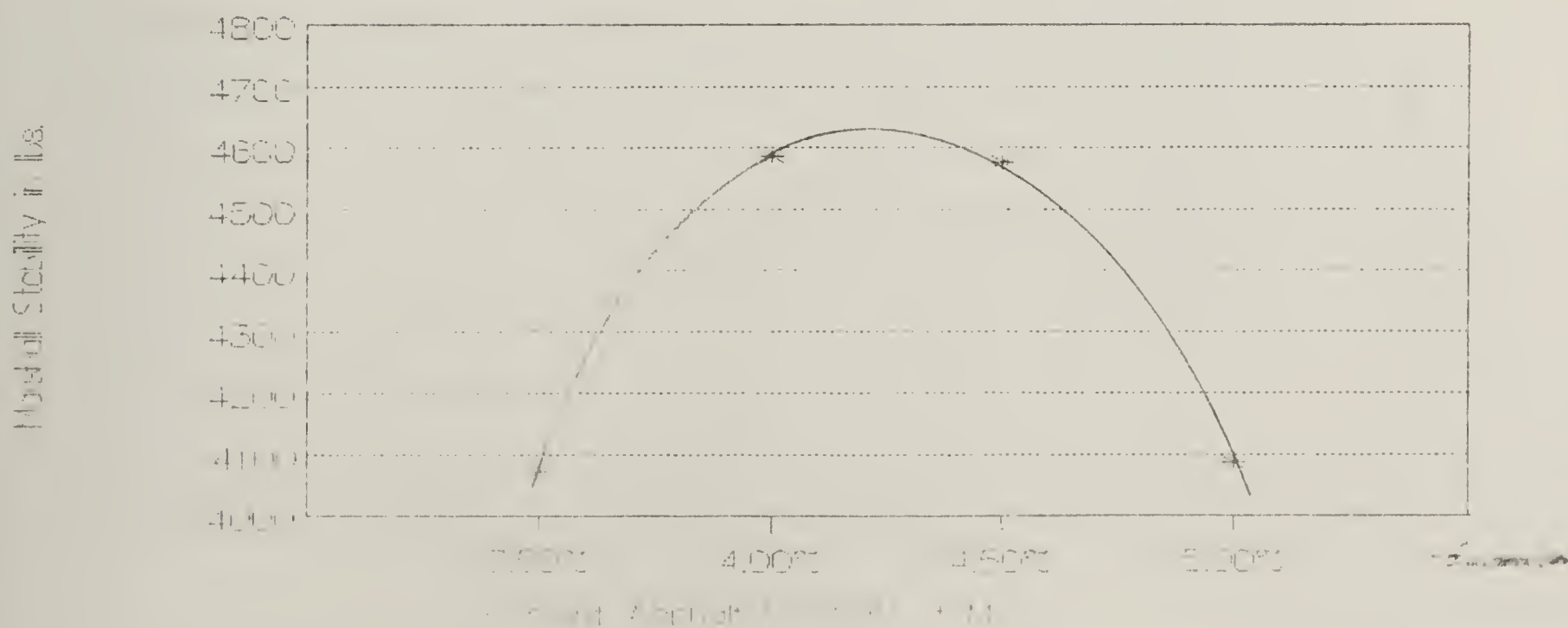
## Polybilt Mod. Cenex - II Gradation Agg.

75 Blow - Marshall Flow in 1/100 Inch.

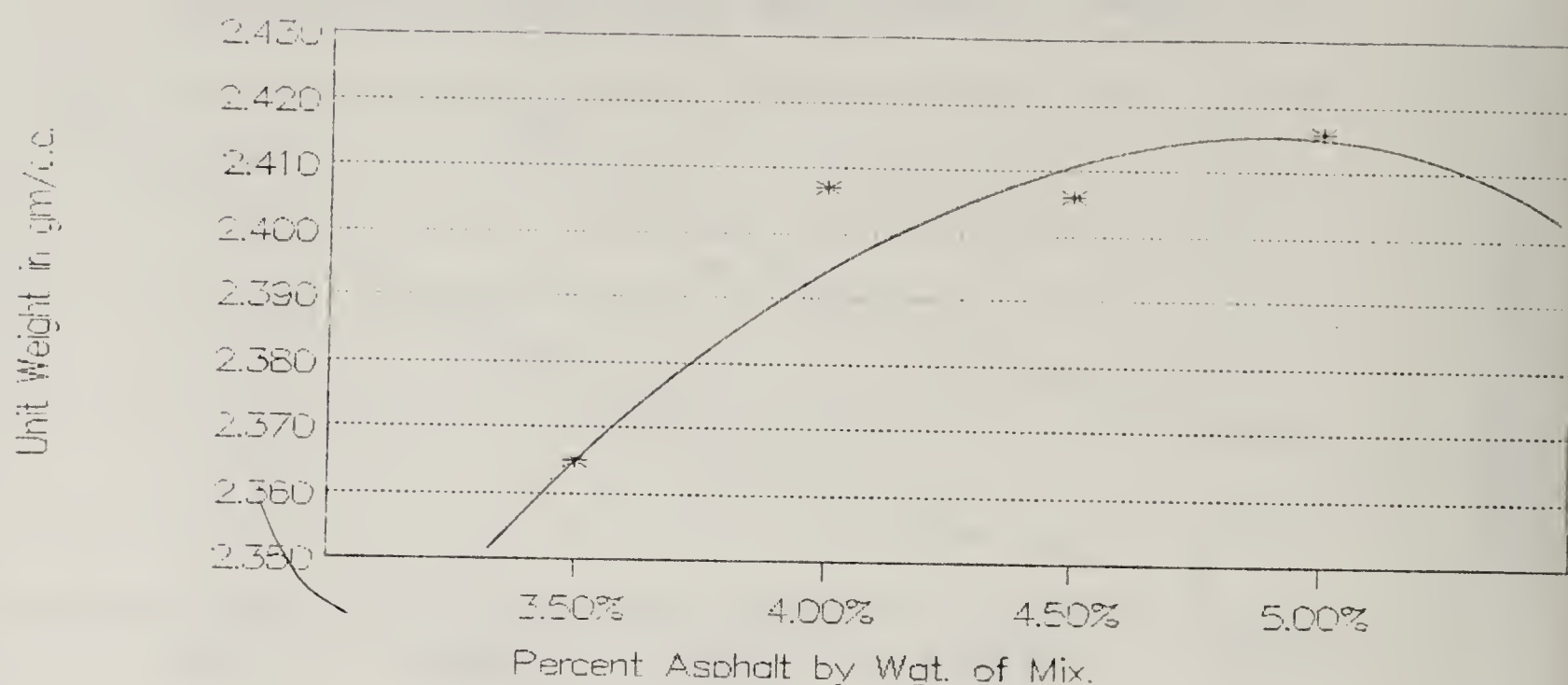


## Polybilt Mod. Cenex - II Gradation Agg.

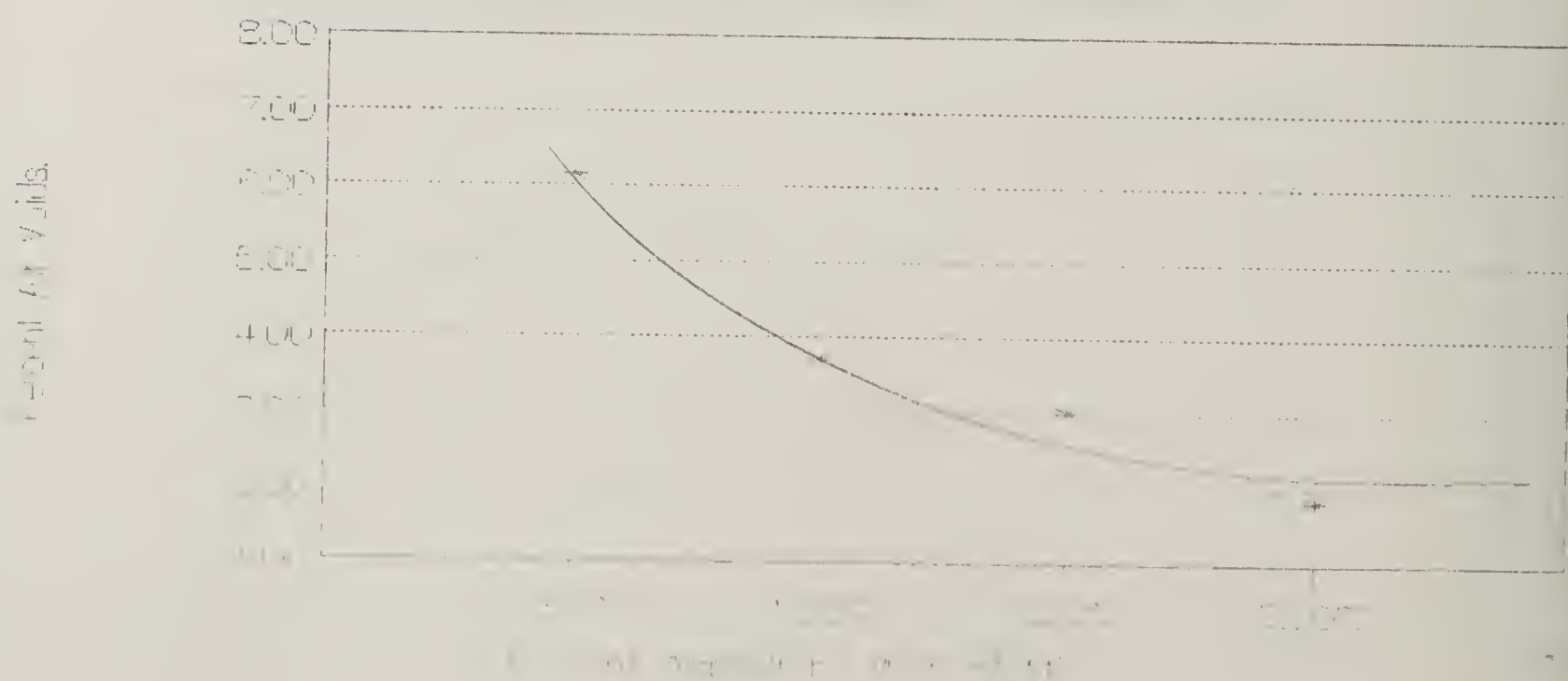
75 Blow - Marshall Stability in lbs.



# Polybilt Mod. Cenex — II Gradation Agg. 75 Blow — Unit Weight in gm/c.c.

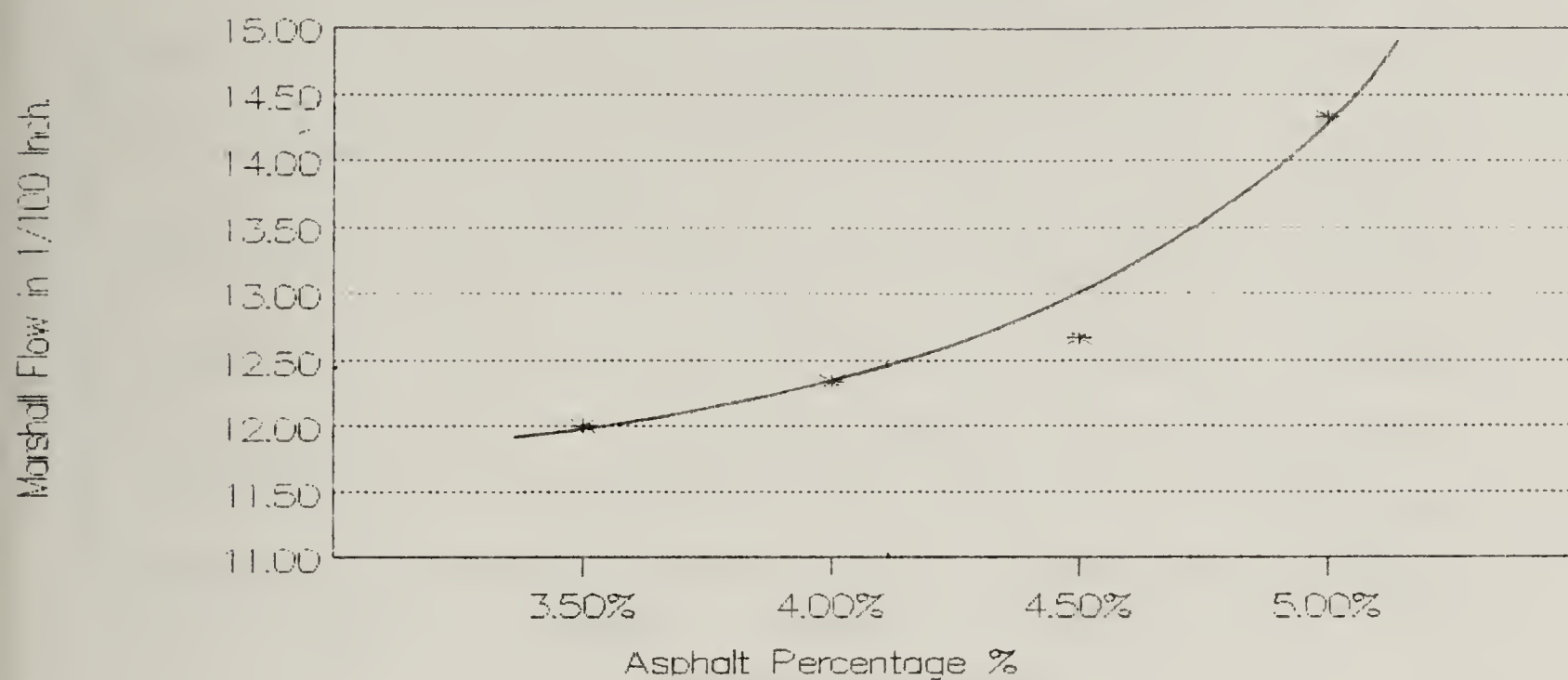


# Polybilt Mod. Cenex — II Gradation Agg. 75 Blow — Percent Air Voids.



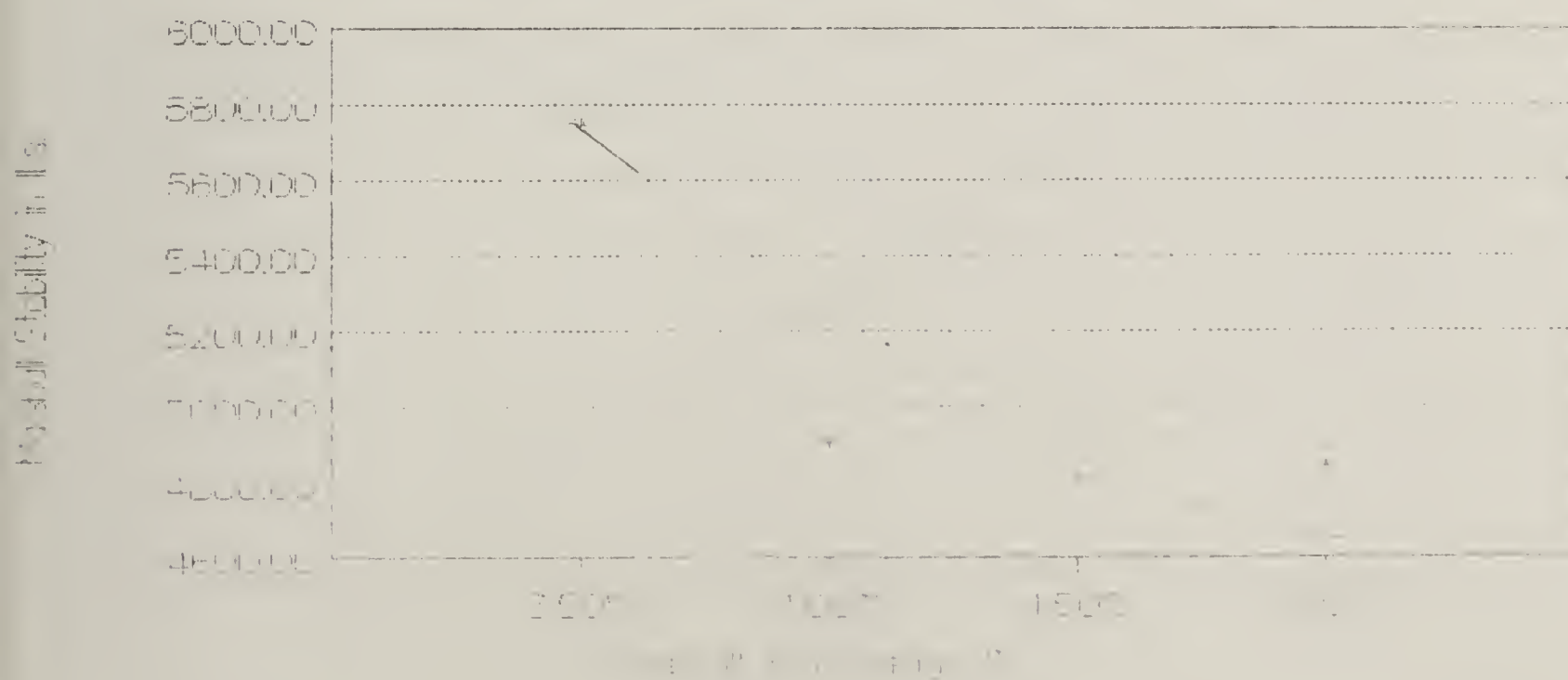
# Unmodified Cenex - II Gradation Agg.

Marshall Flow in 1/100 Inch (112-Blow).



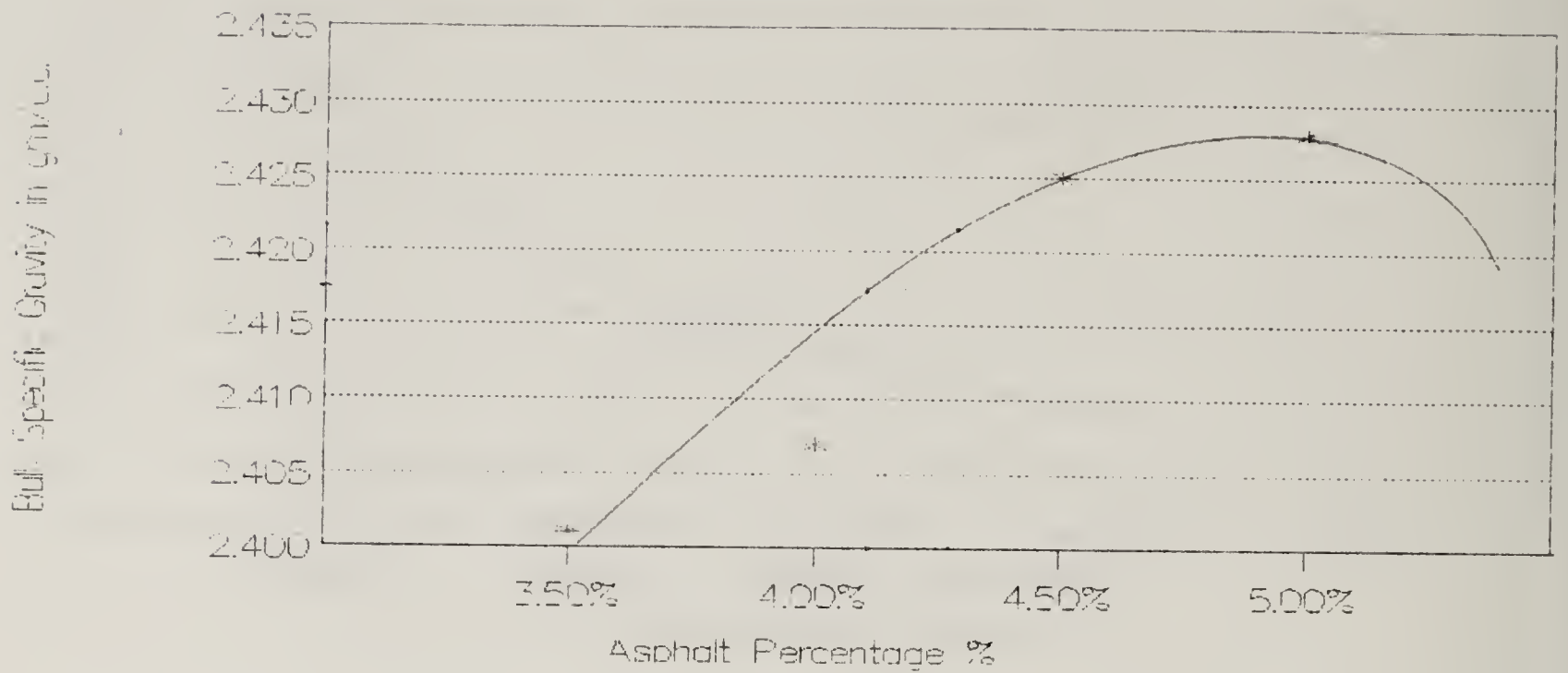
# Unmodified Cenex - II Gradation Agg.

Marshall Stability in lbs. (112-Blow).



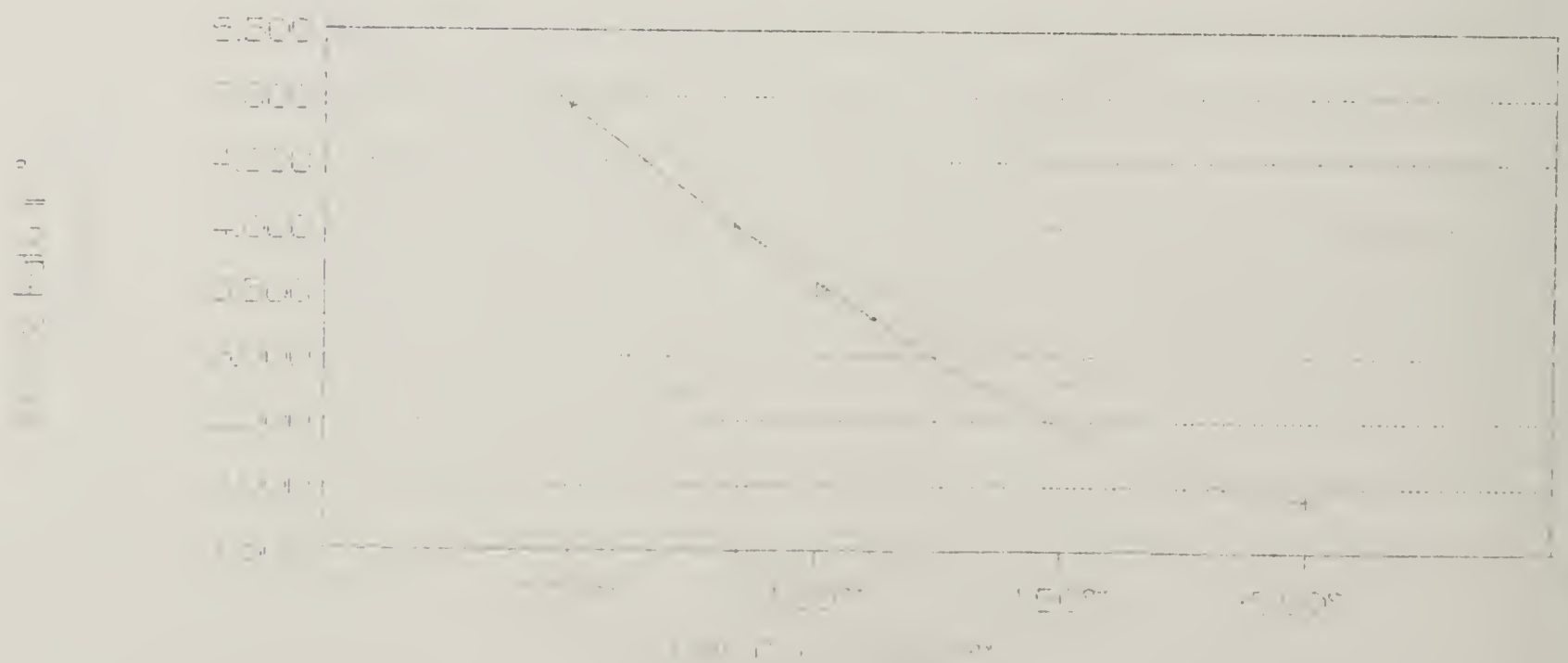
## Unmodified Cenex - II Gradation Agg.

Bulk Specific Gravity (112-Blow).



## Unmodified Cenex - II Gradation Agg.

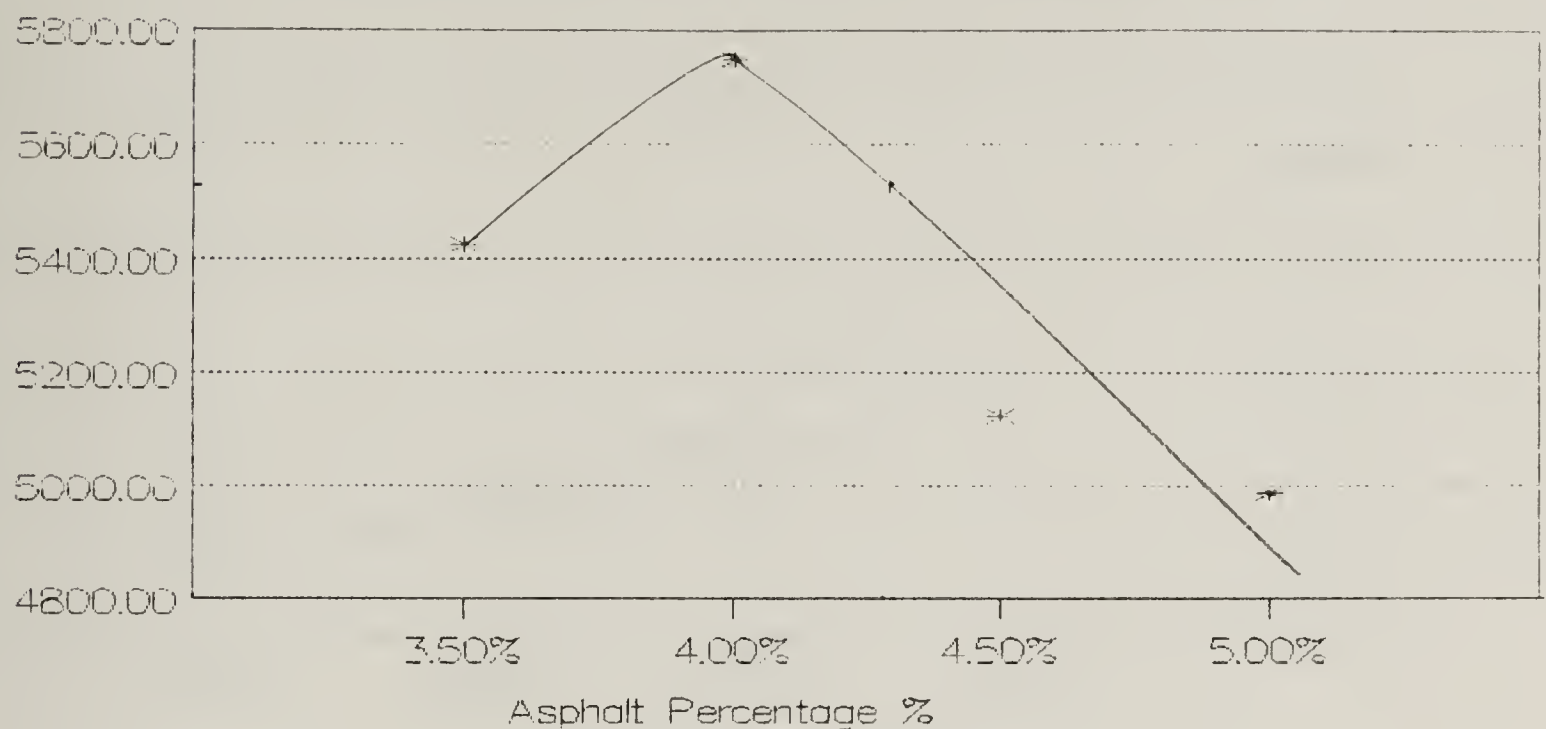
Air Void Ratio in % (112-Blow).



# Kraton Mod. Cenex - II Gradation Agg.

112 Blows - Marshall Stability in lbs.

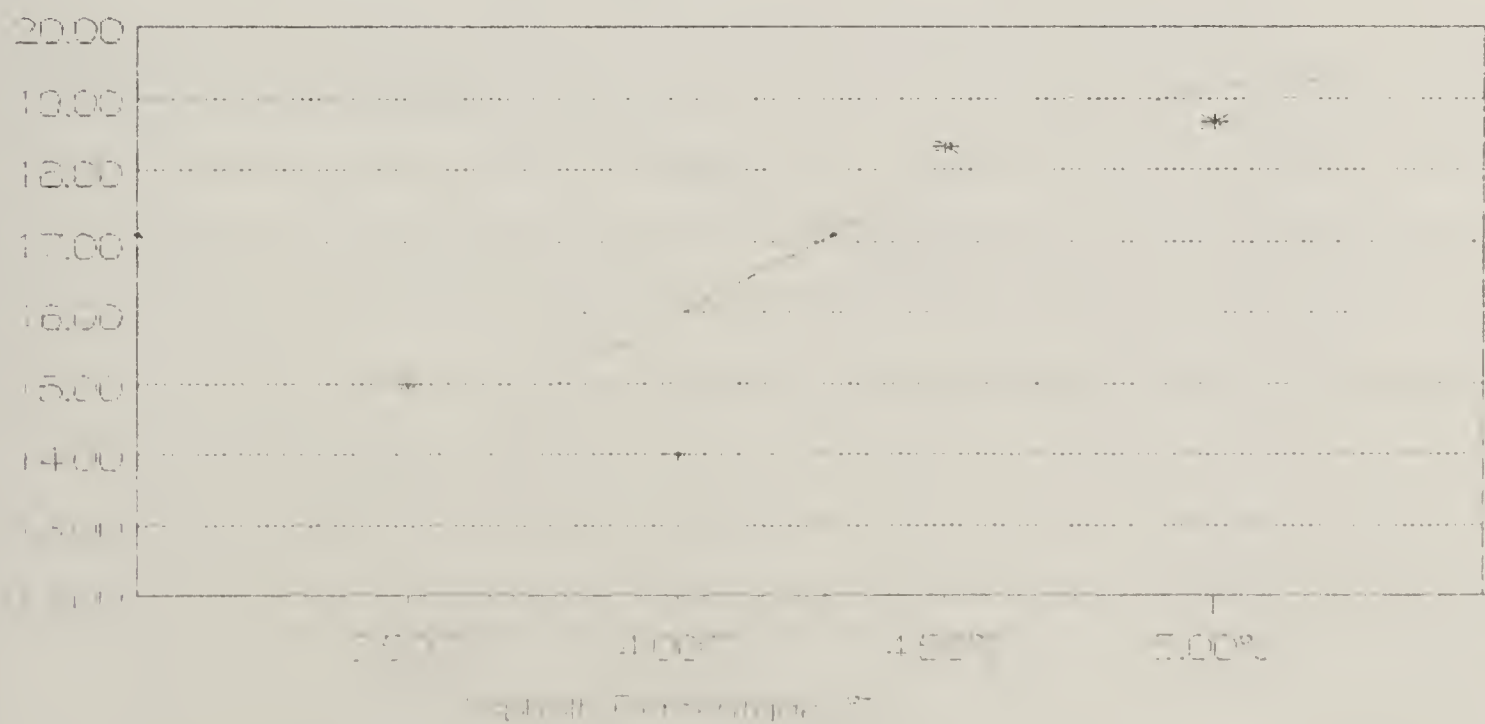
Marshall Stability in lbs.



# Kraton Mod. Cenex - II Gradation Agg.

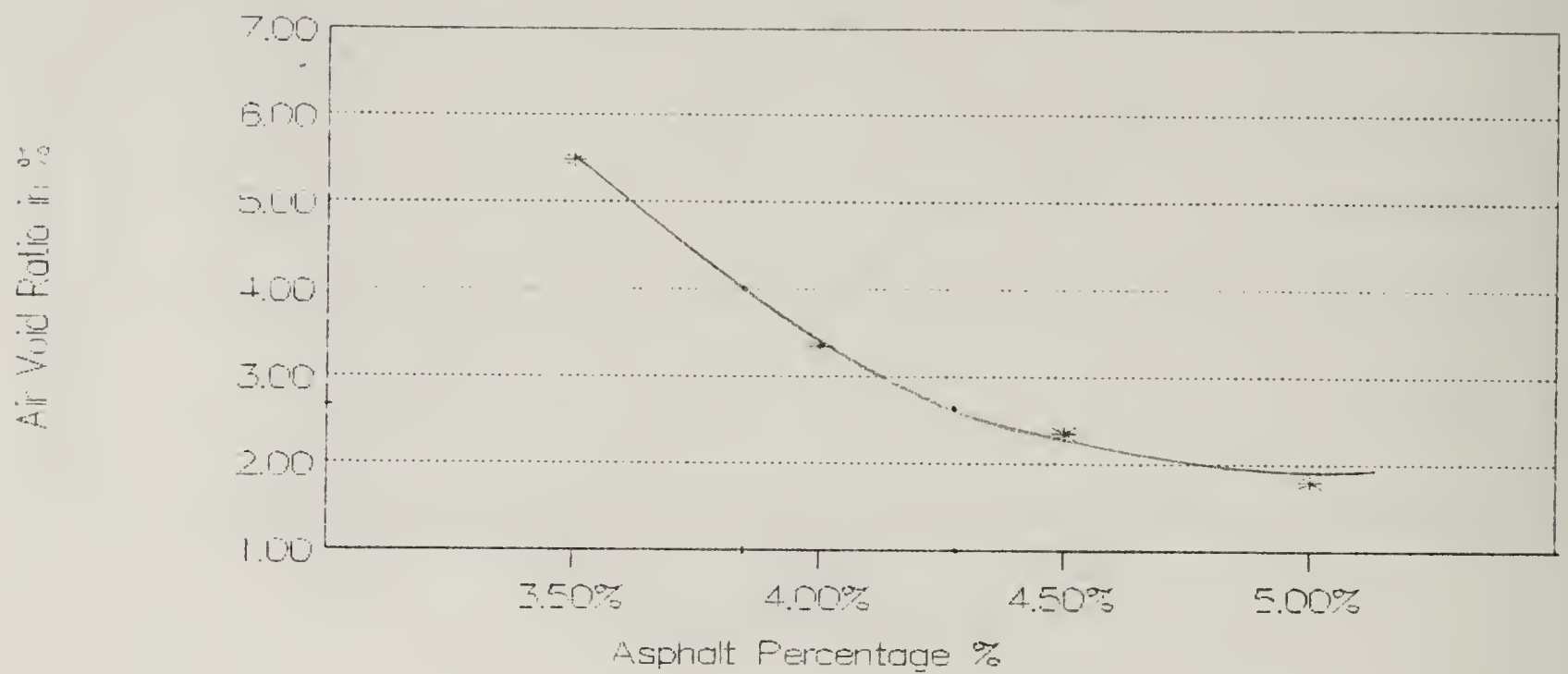
112 Blows - Marshall Flow in 1/100 Inch

Marshall Flow in 1/100 Inch



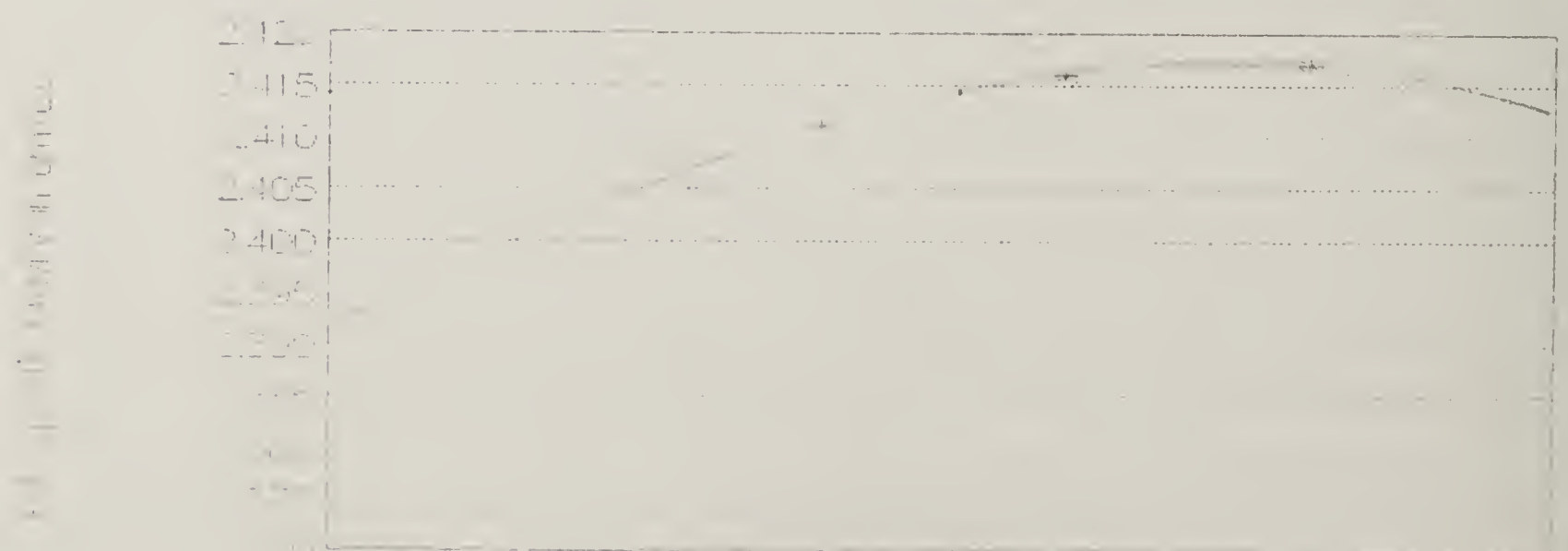
# Kraton Mod. Cenex - II Gradation Agg.

112 Blows - Air Void Ratio in %



# Kraton Mod. Cenex - II Gradation Agg.

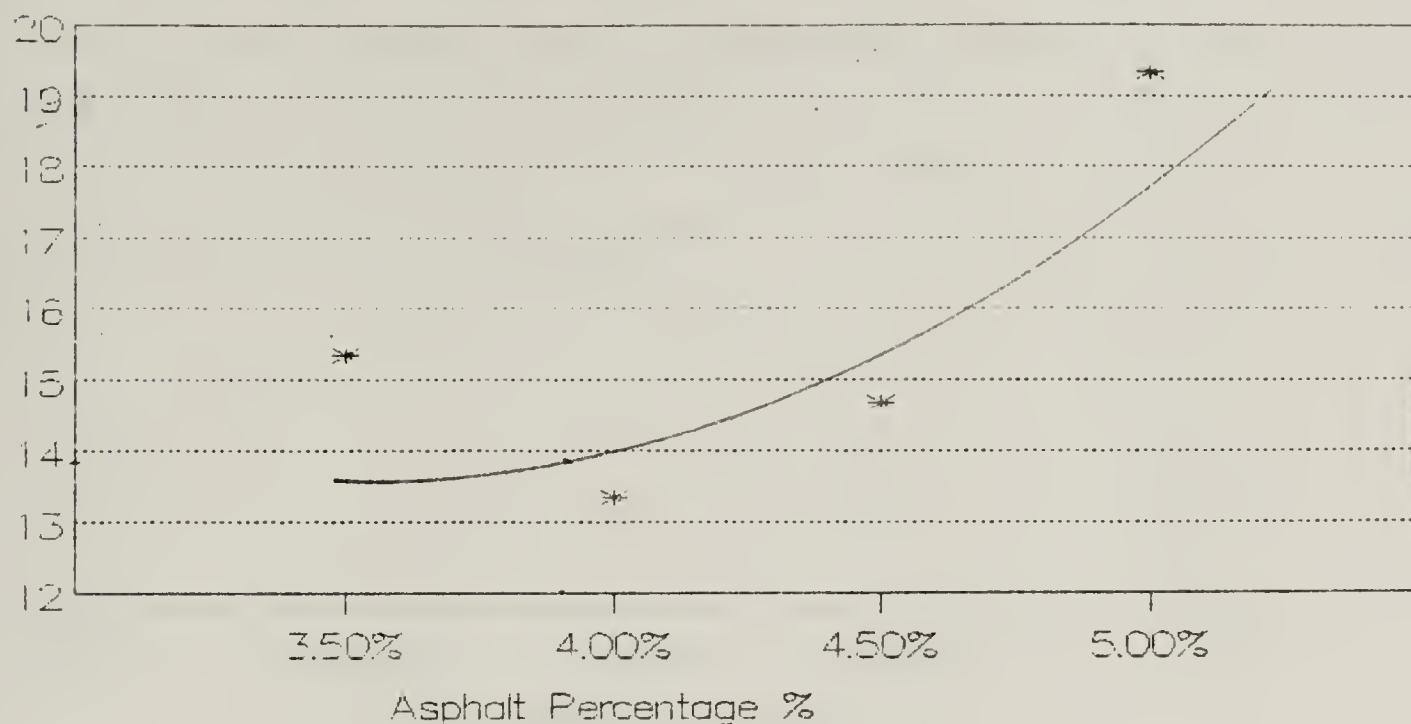
112 Blows - Bulk Specific Gravity



# Polybilt Mod. Cenex - II Gradation Agg.

112 Blows - Marshall Flow in 1/100 Inch

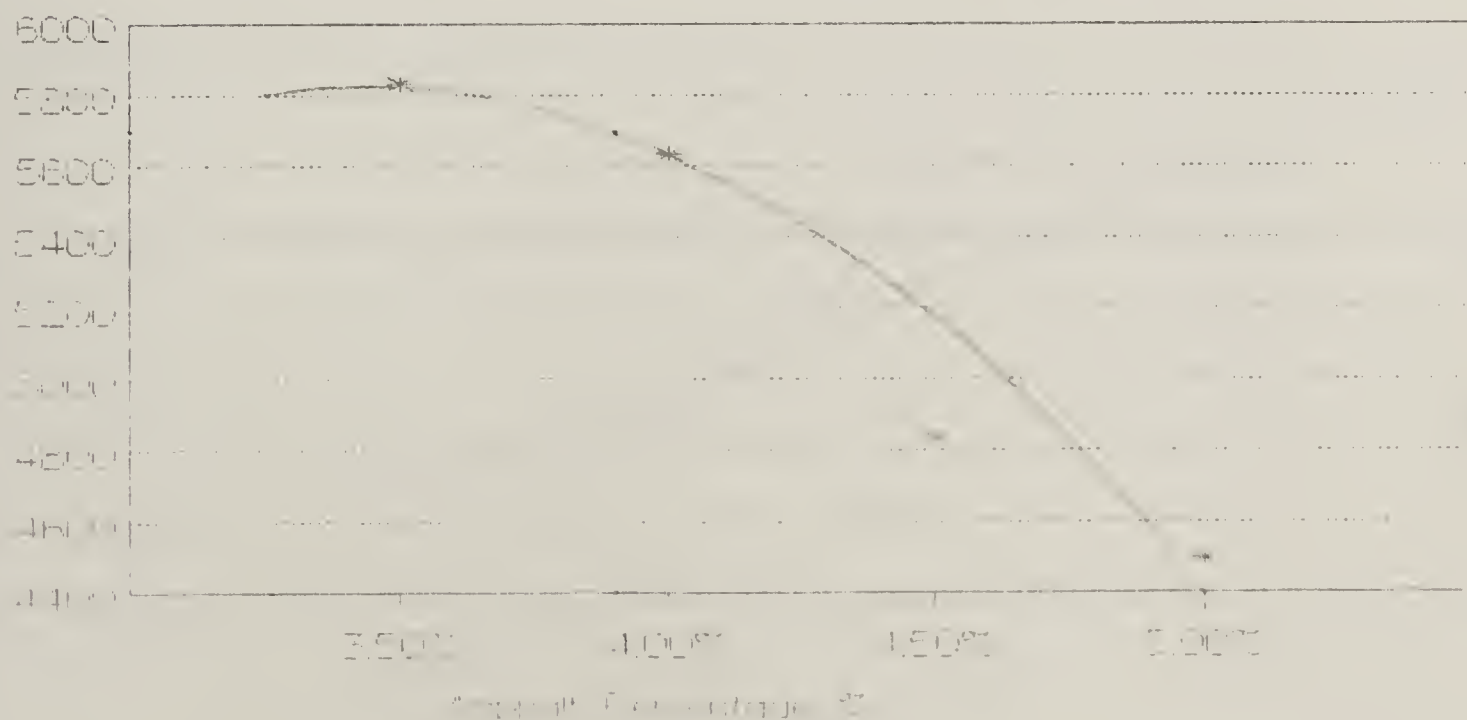
Marshall Flow in 1/100 Inch



# Polybilt Mod. Cenex - II Gradation Agg.

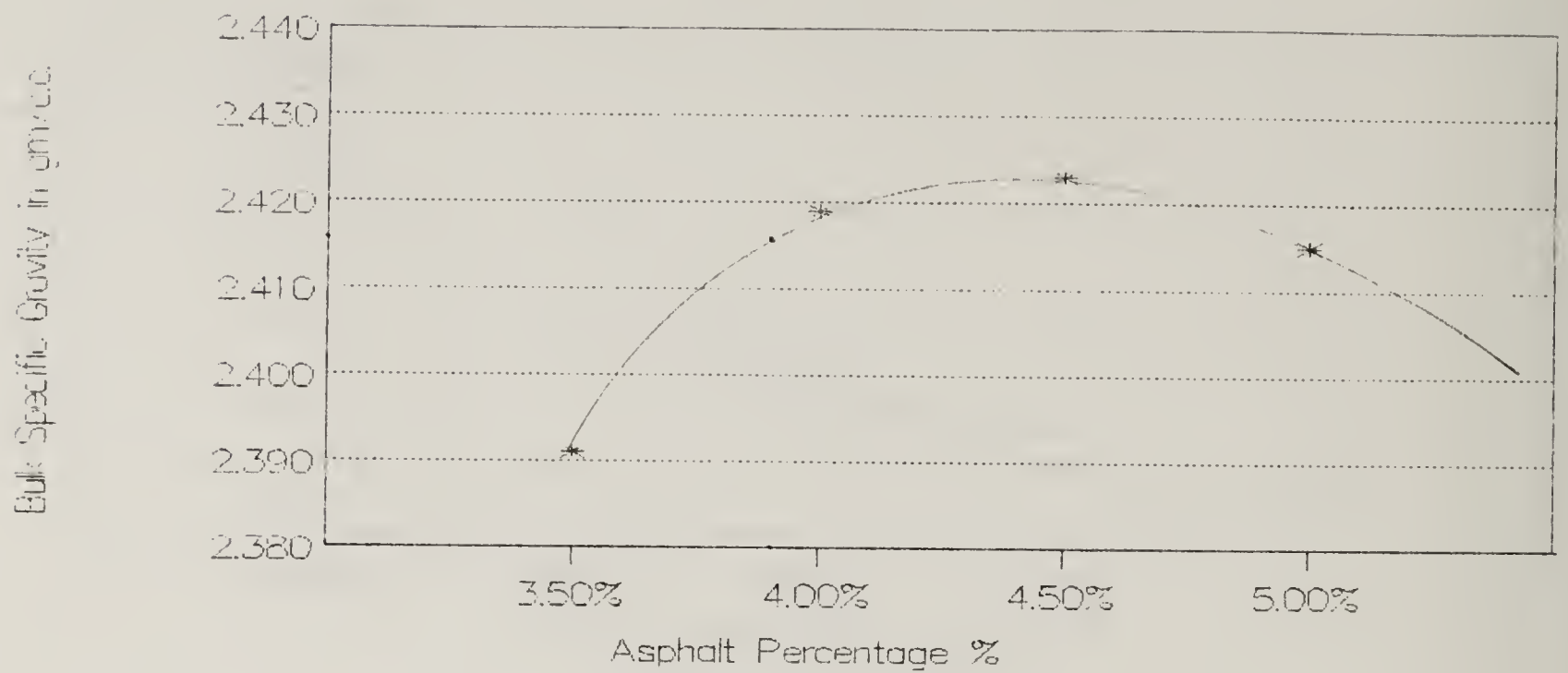
112 Blows - Marshall Stability in lbs.

Marshall Stability in lbs.



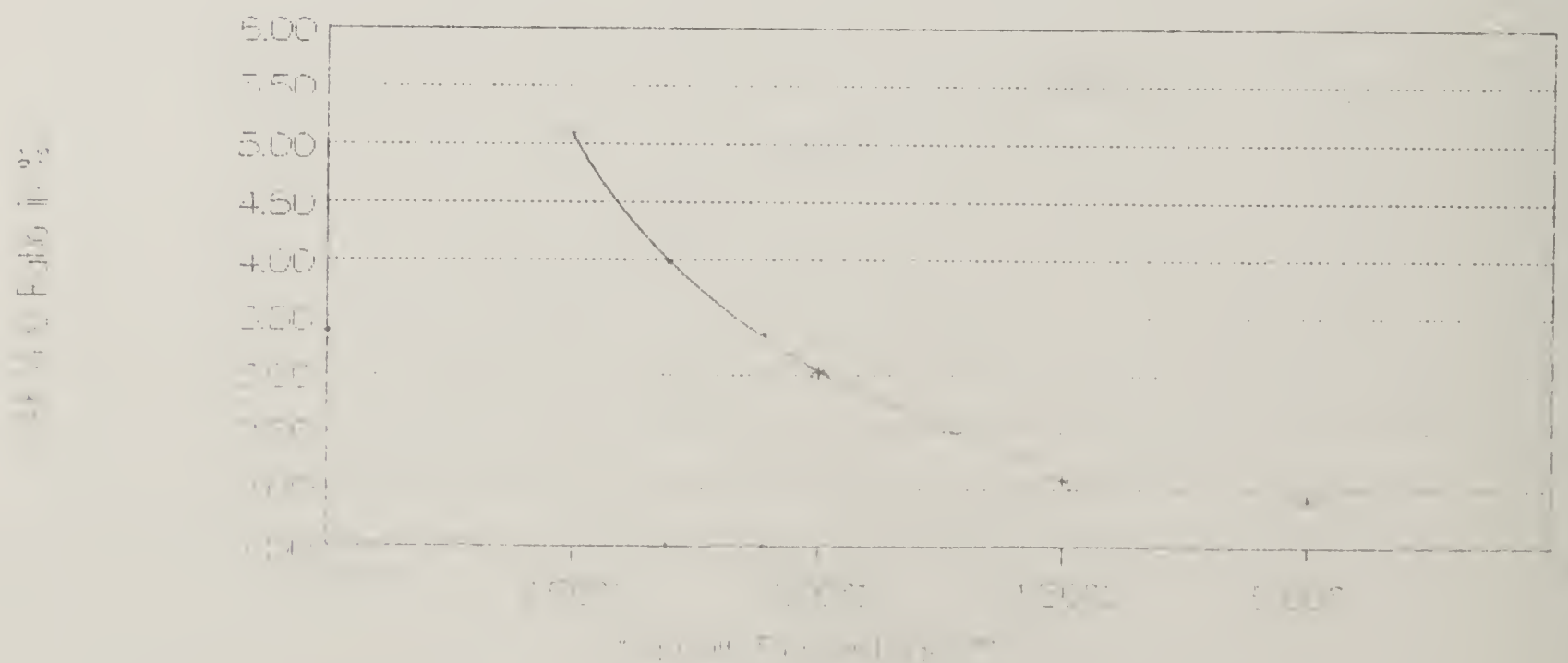
# Polybilt Mod. Cenex - II Gradation Agg.

112 Blows - Bulk Specific Gravity



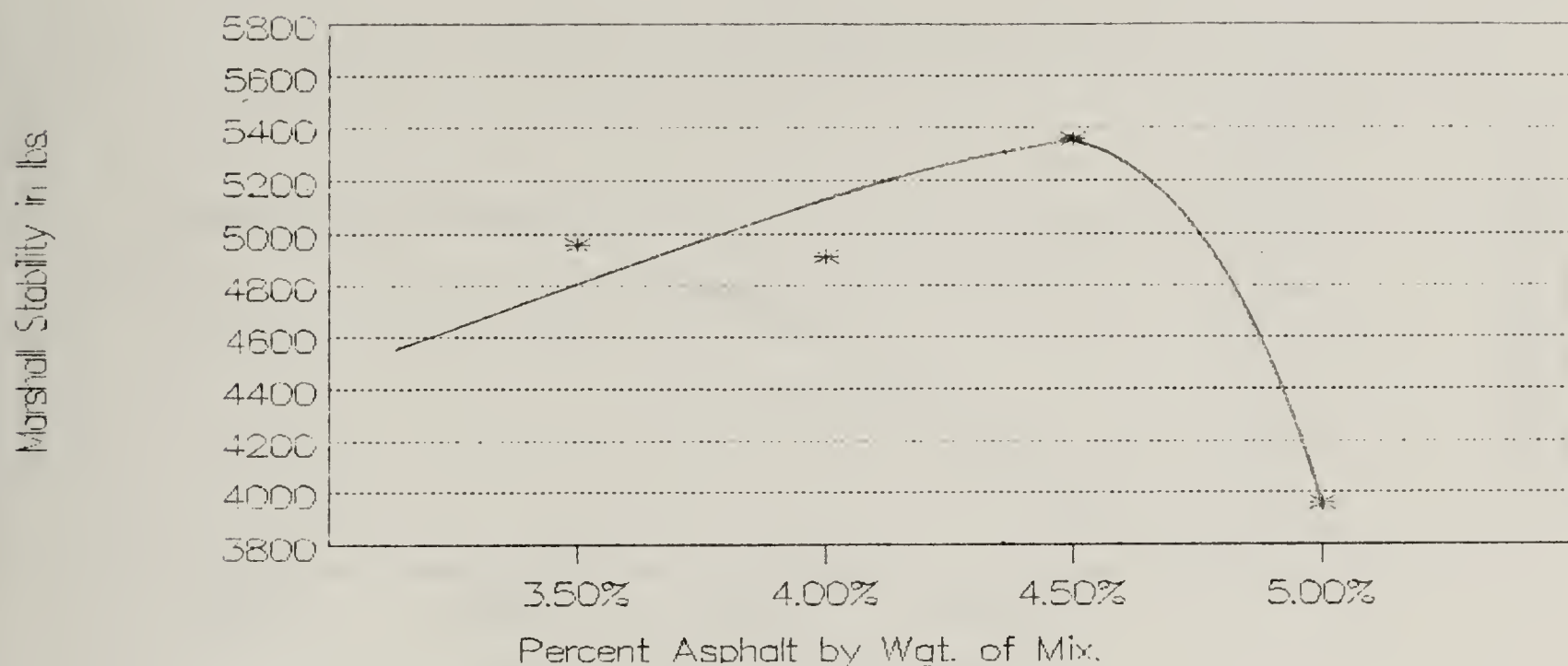
# Polybilt Mod. Cenex - II Gradation Agg.

112 Blows - Air Void Ratio in %



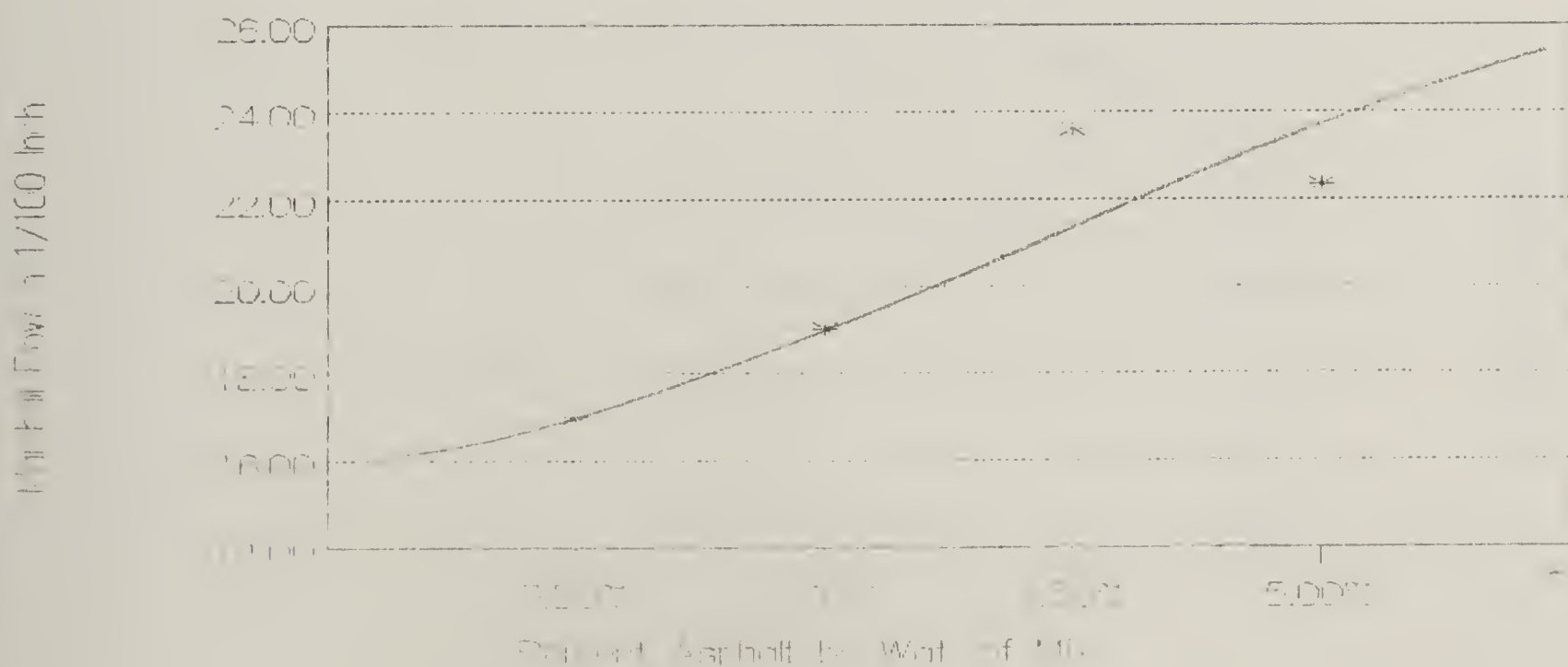
## Unmodified Cenex - II Gradation Agg.

### Miller Filler - Marshall Stability.



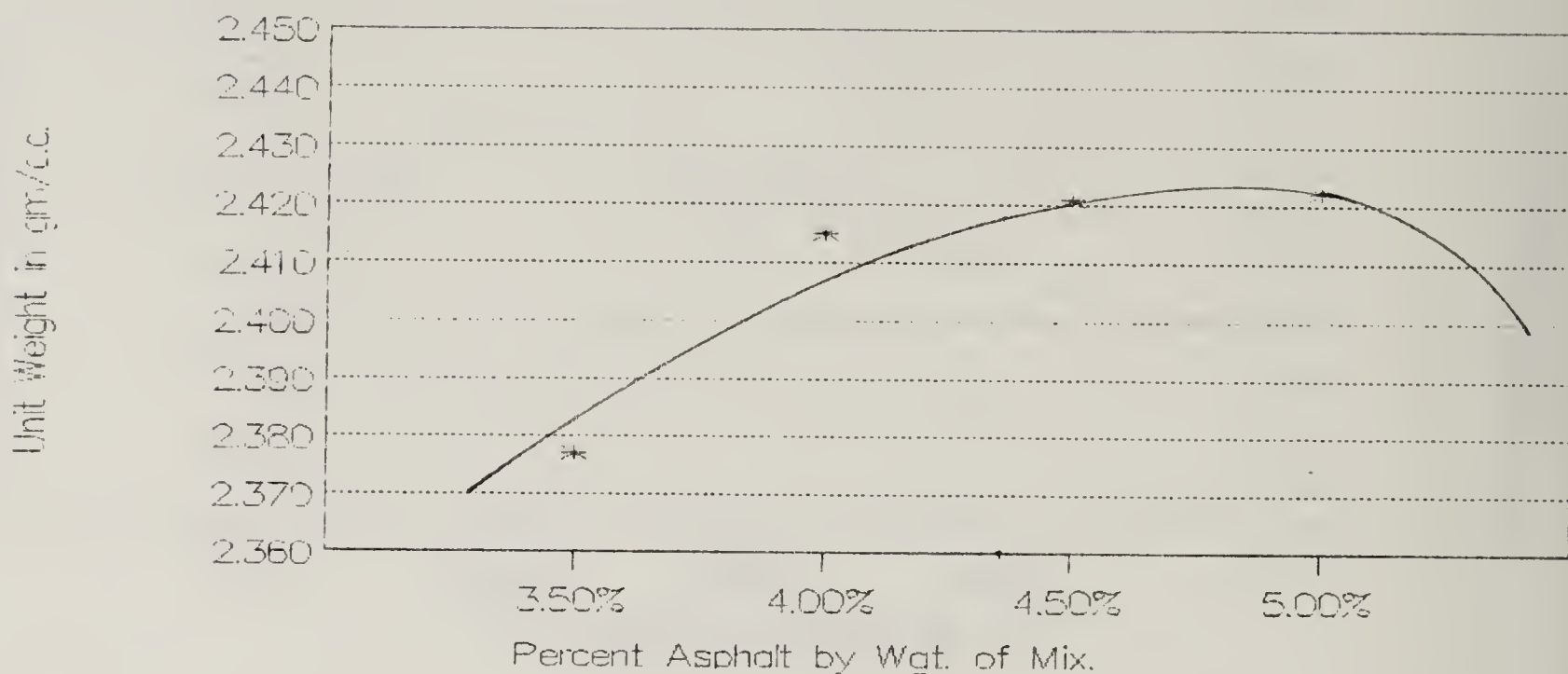
## Unmodified Cenex - II Gradation Agg.

### Miller Filler - Marshall Flow.



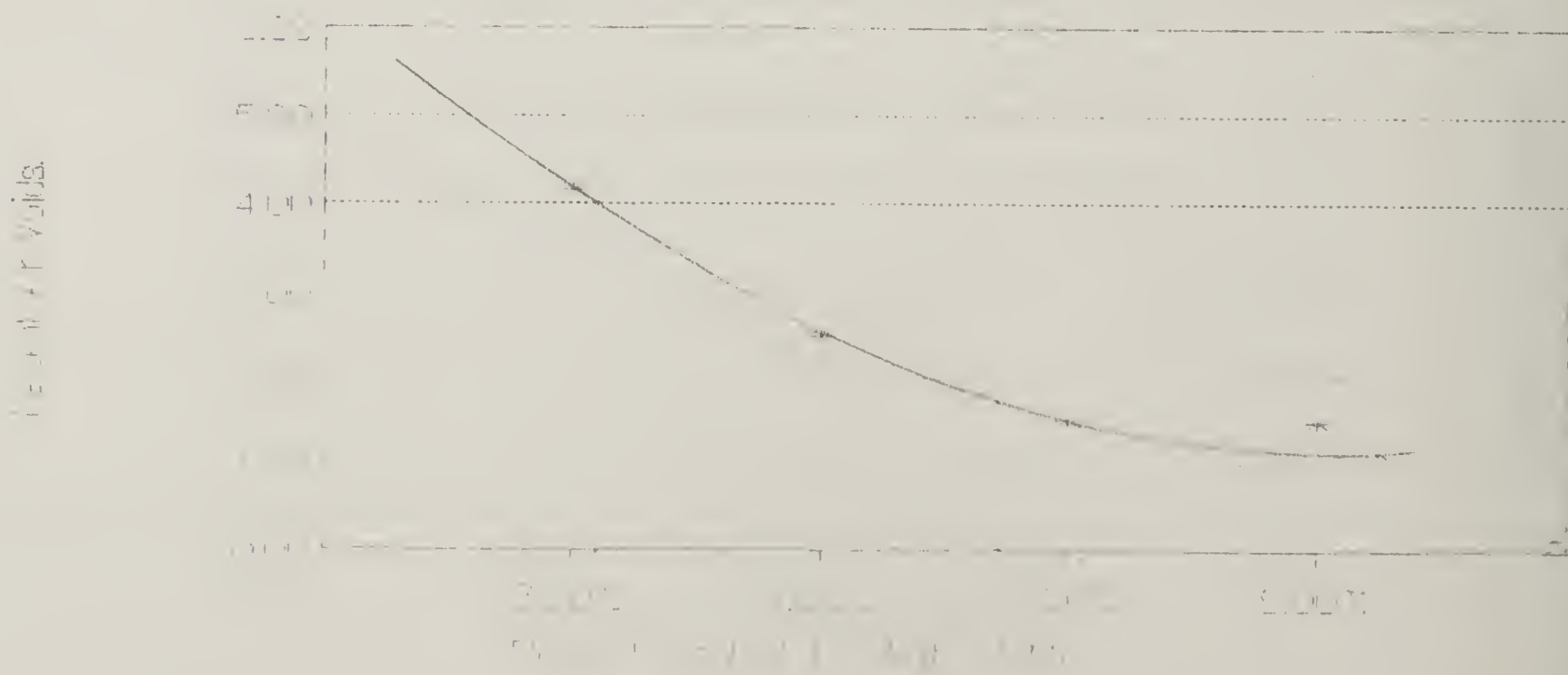
# Unmodified Cenex - II Gradation Agg.

Miller Filler - Unit Weight in gm/c.c.

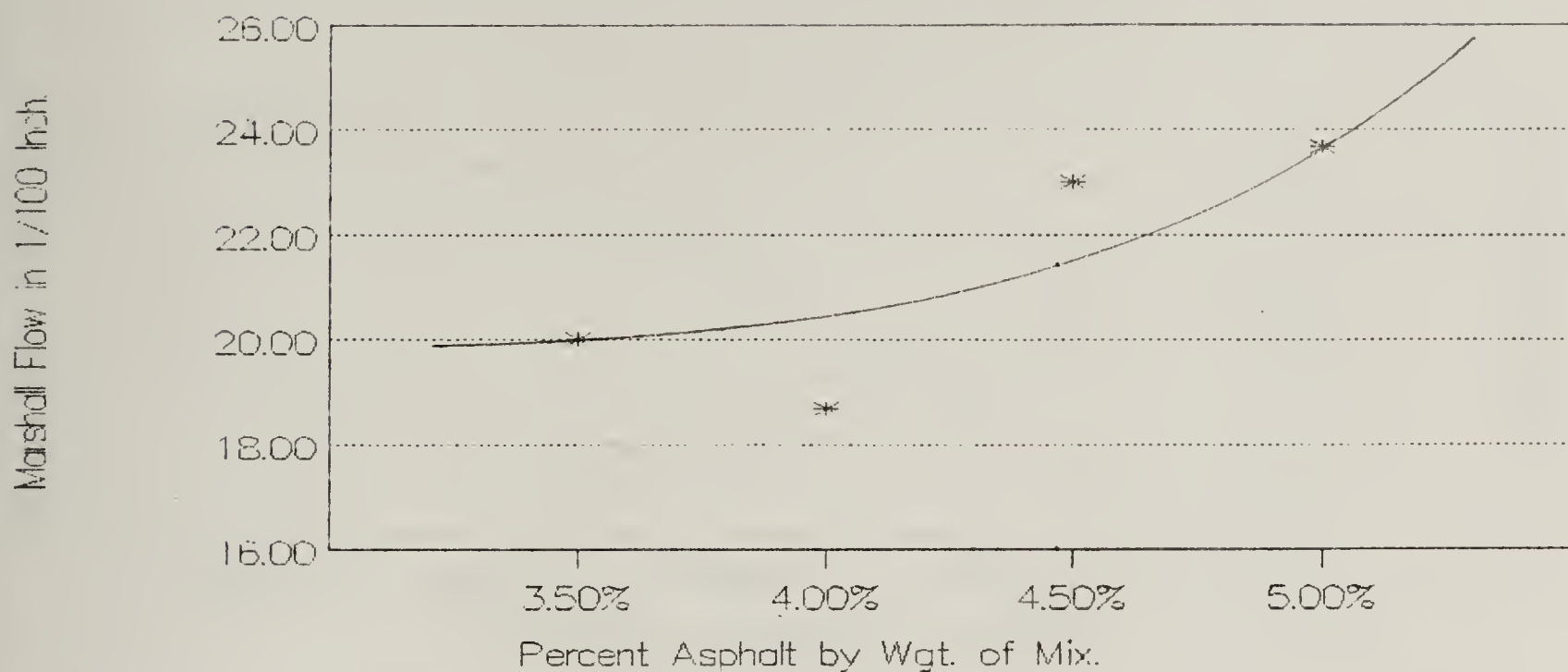


# Unmodified Cenex - II Gradation Agg.

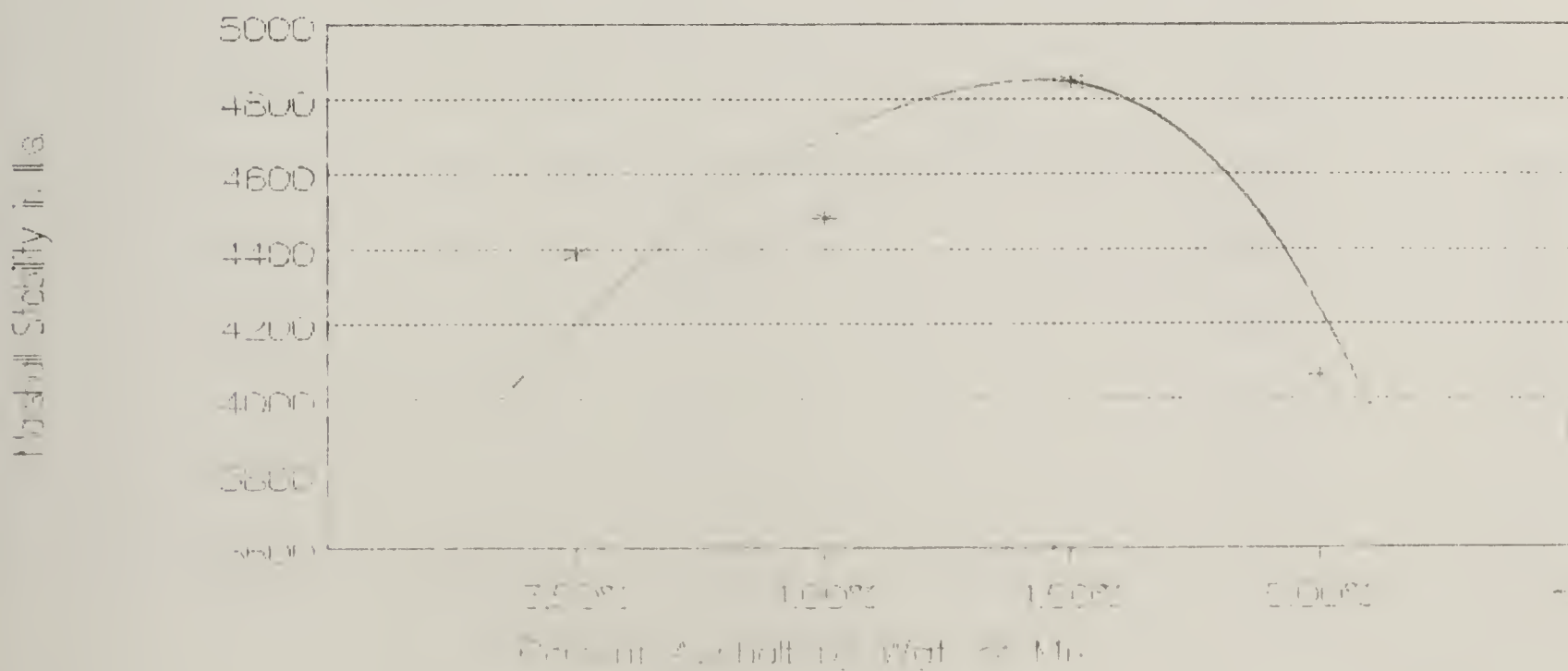
Miller Filler - Percent Air Voids.



# Kraton Mod. Cenex - II Gradation Agg. Miller Filler - Marshall Flow.

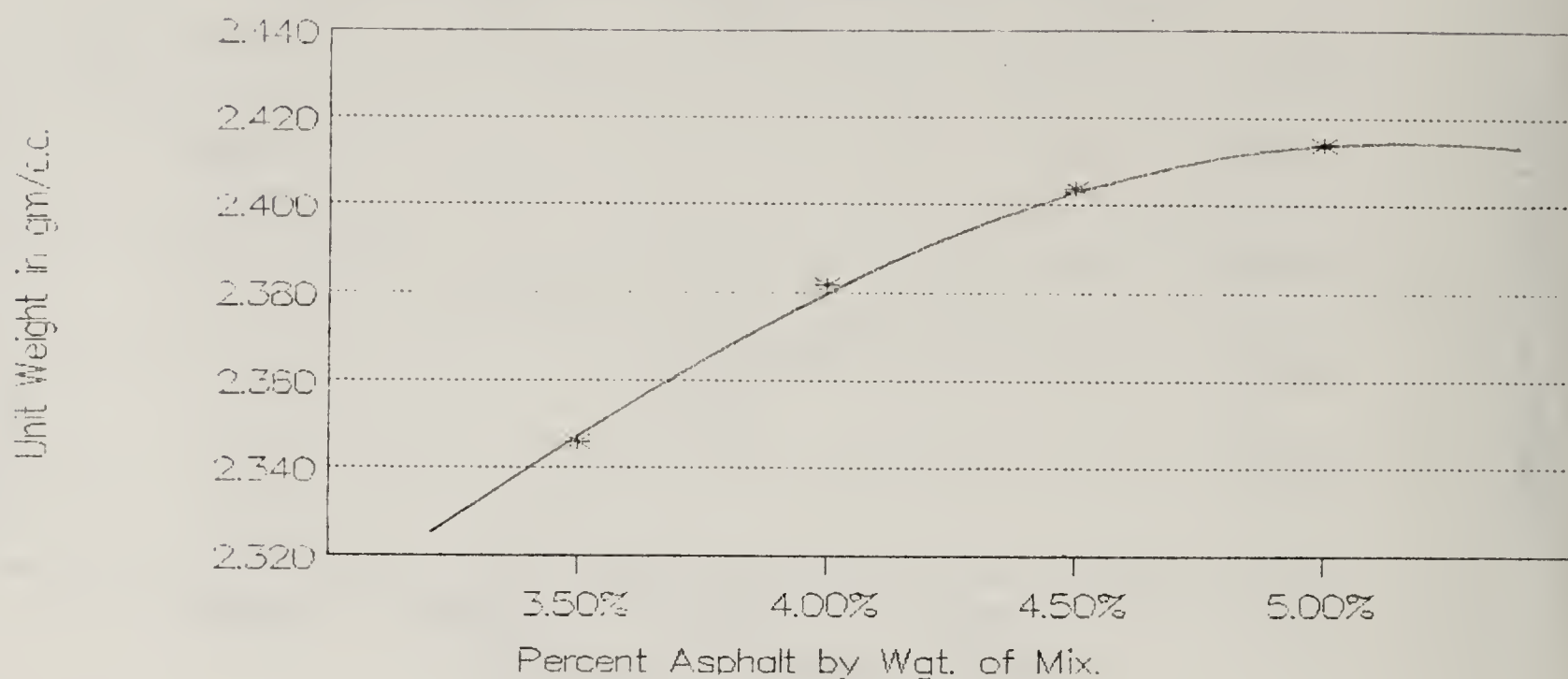


# Kraton Mod. Cenex - II Gradation Agg. Miller Filler - Marshall Stability.



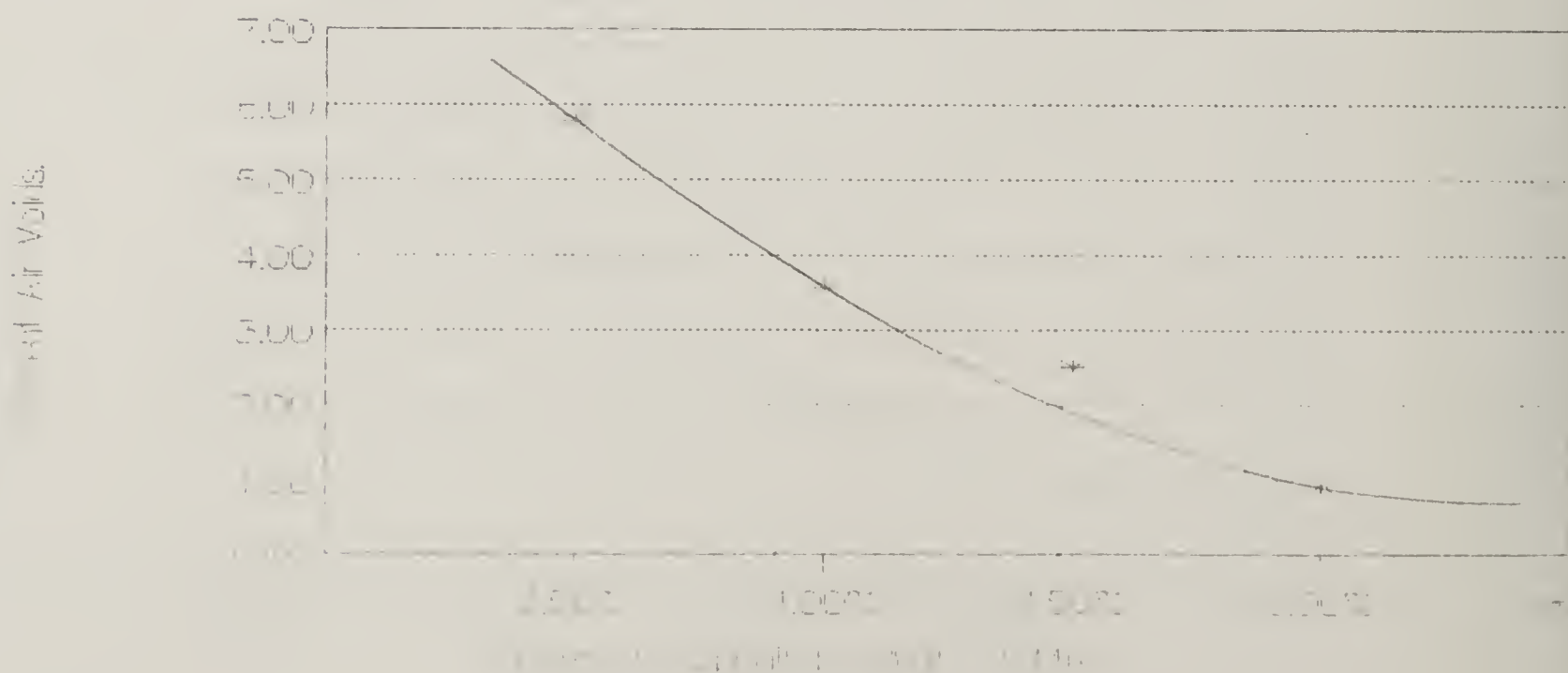
## Kraton Mod. Cenex — II Gradation Agg.

Miller Filler — Unit Weight in gm/c.c.



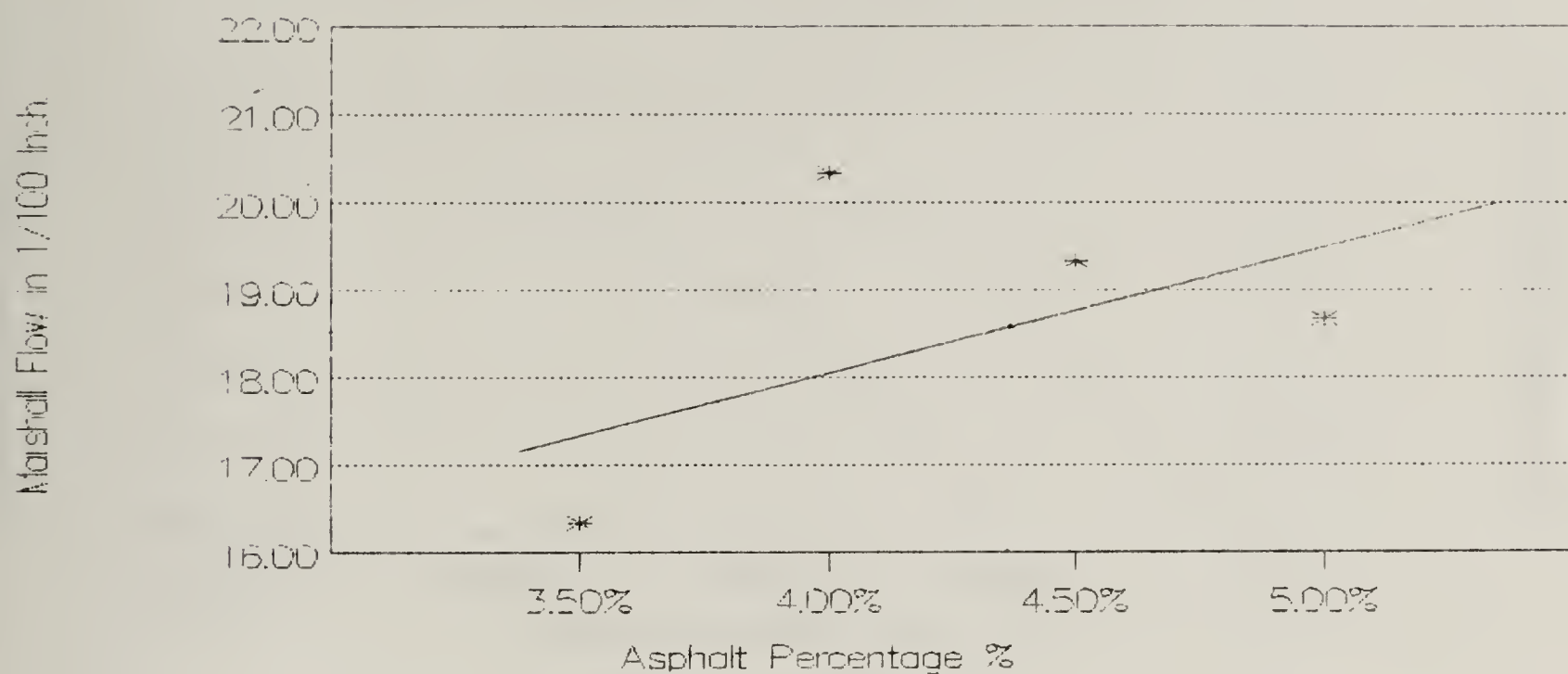
## Kraton Mod. Cenex — II Gradation Agg.

Miller Filler — Percent Air Voids.



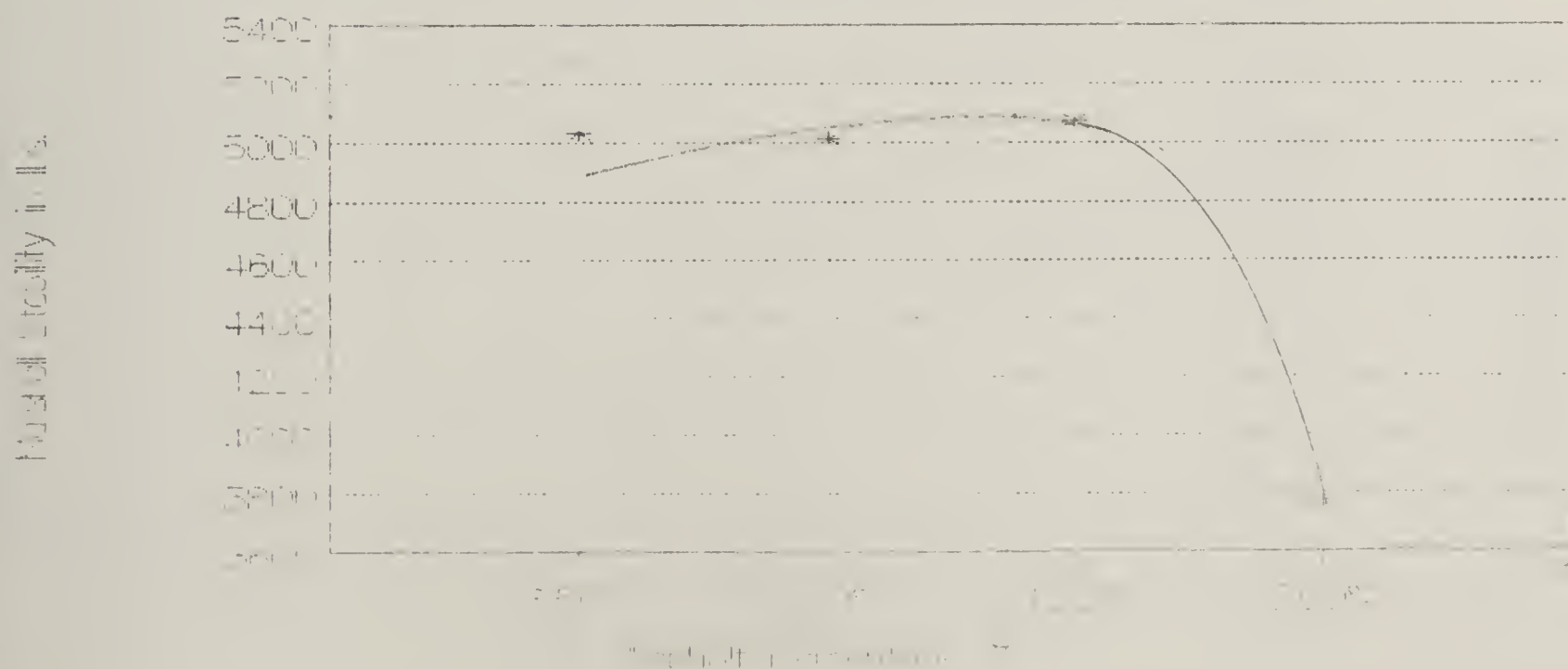
# Polybilt Mod. Cenex - II Gradation Agg.

## Mineral Filler - Marshall Flow



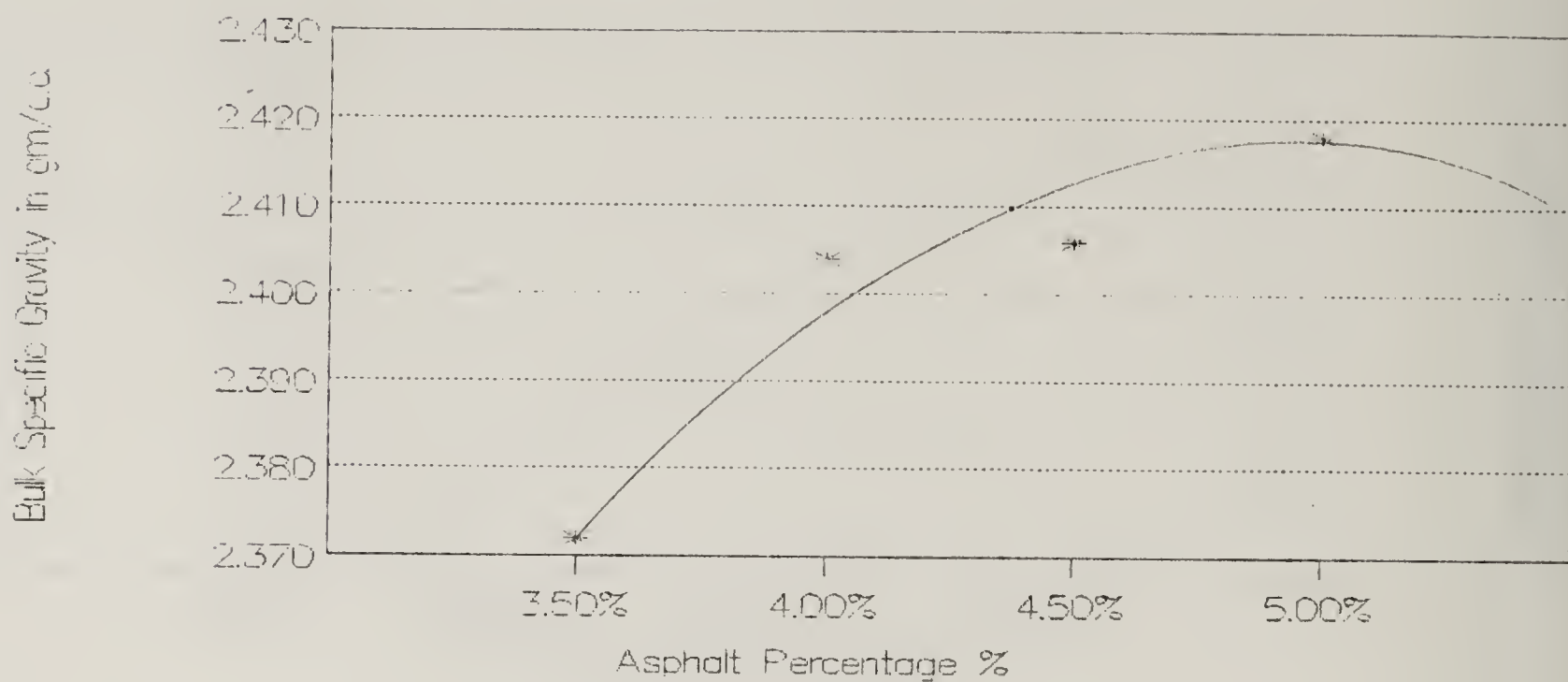
# Polybilt Mod. Cenex - II Gradation Agg.

## Mineral Filler - Marshall Stability



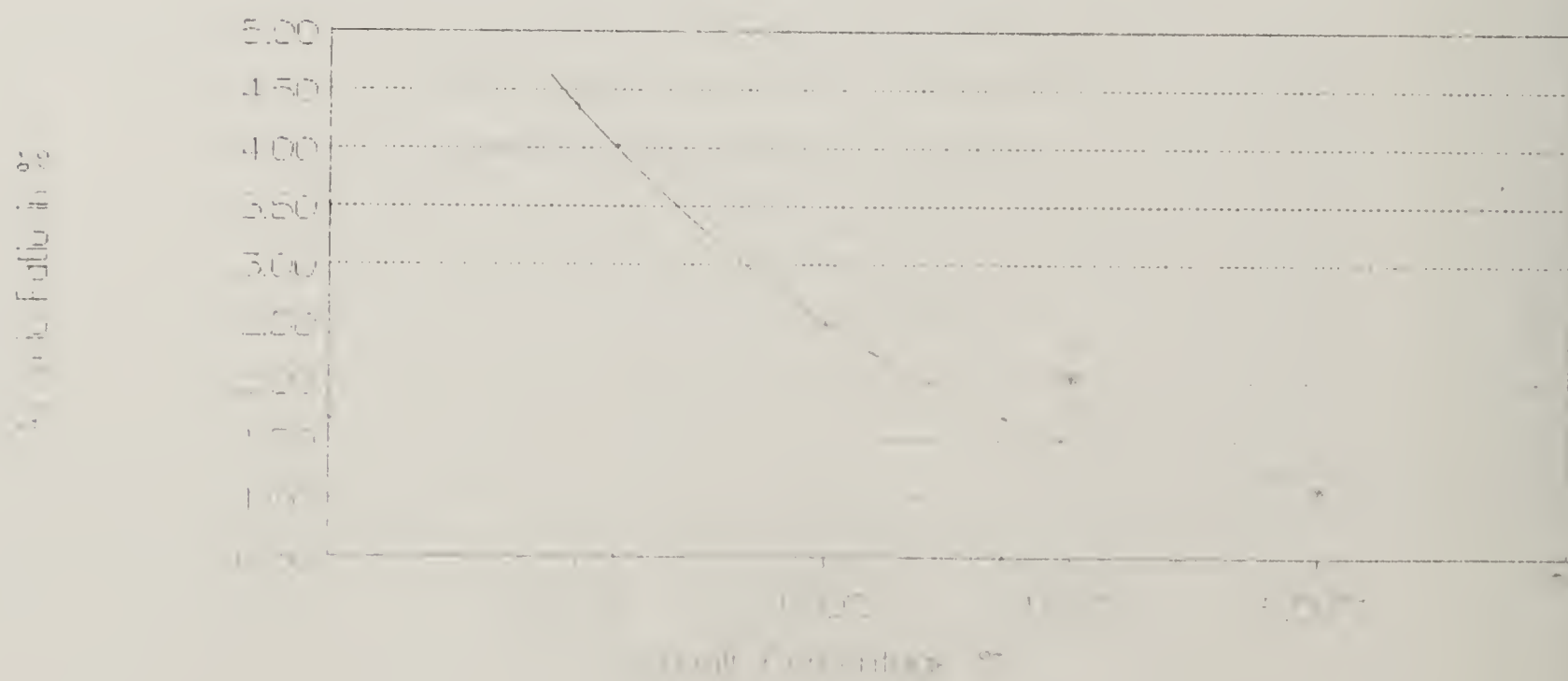
# Polybilt Mod. Cenex — II Gradation Agg.

## Mineral Filler — Bulk Specific Gravity



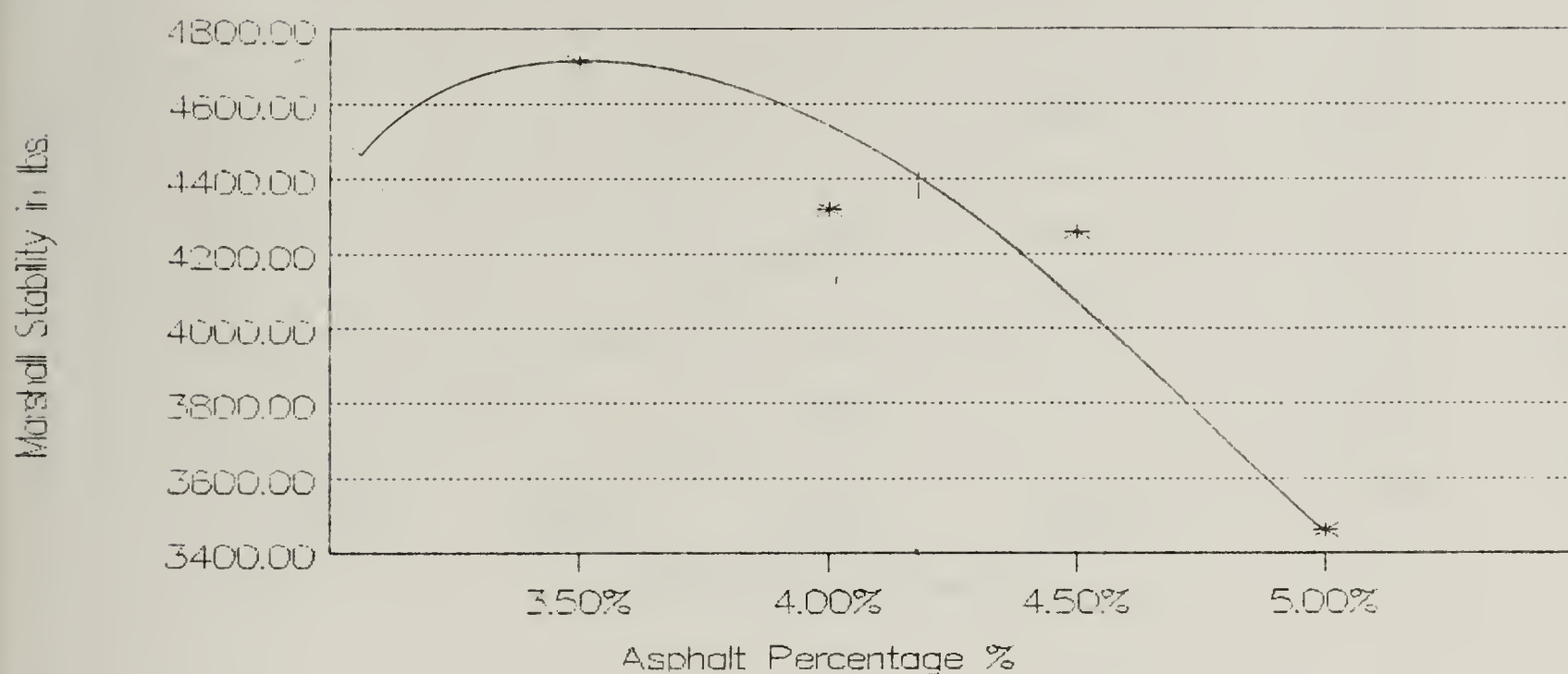
# Polybilt Mod. Cenex — II Gradation Agg.

## Mineral Filler — Air Void Ratio in %



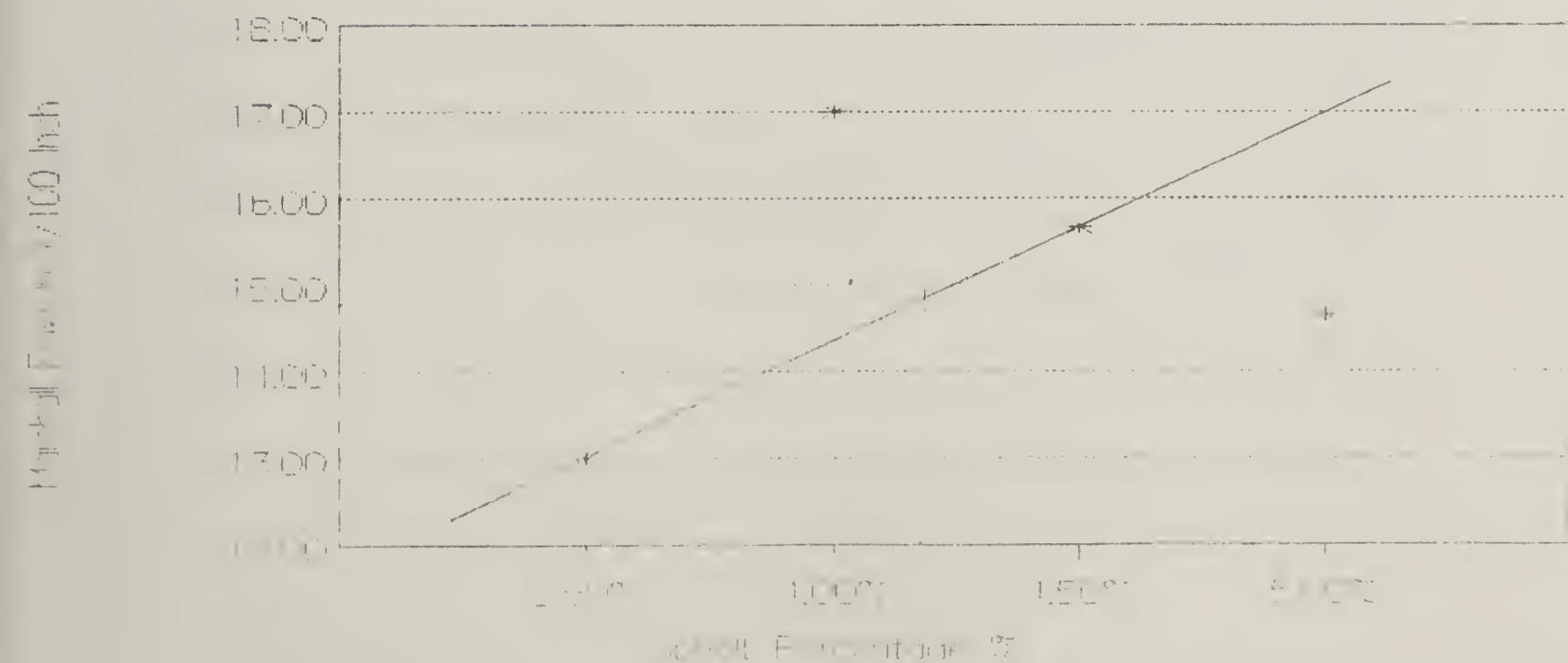
# Unmodified Conoco - II Gradation Agg.

Marshall Stability in lbs. (75-Blow).



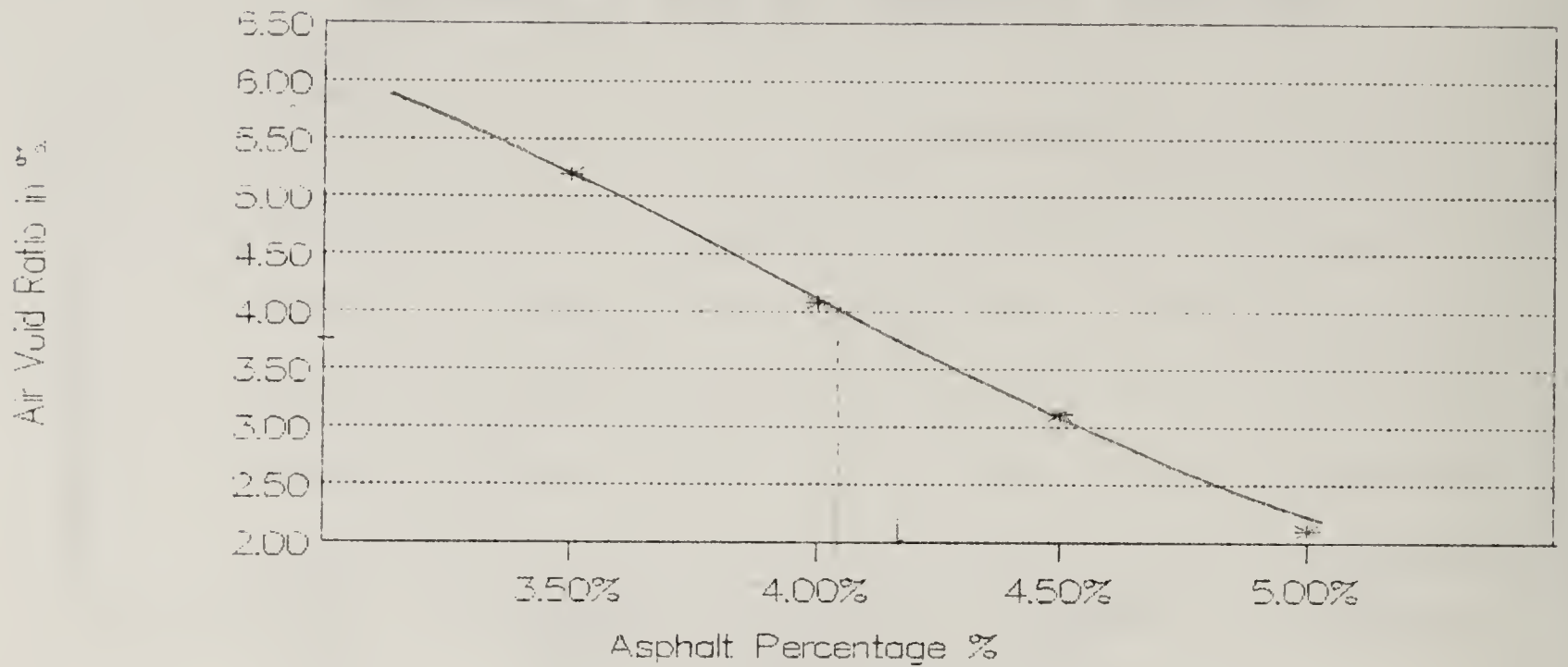
# Unmodified Conoco - II Gradation Agg.

Marshall Flow in 1/100 Inch (75-Blow).



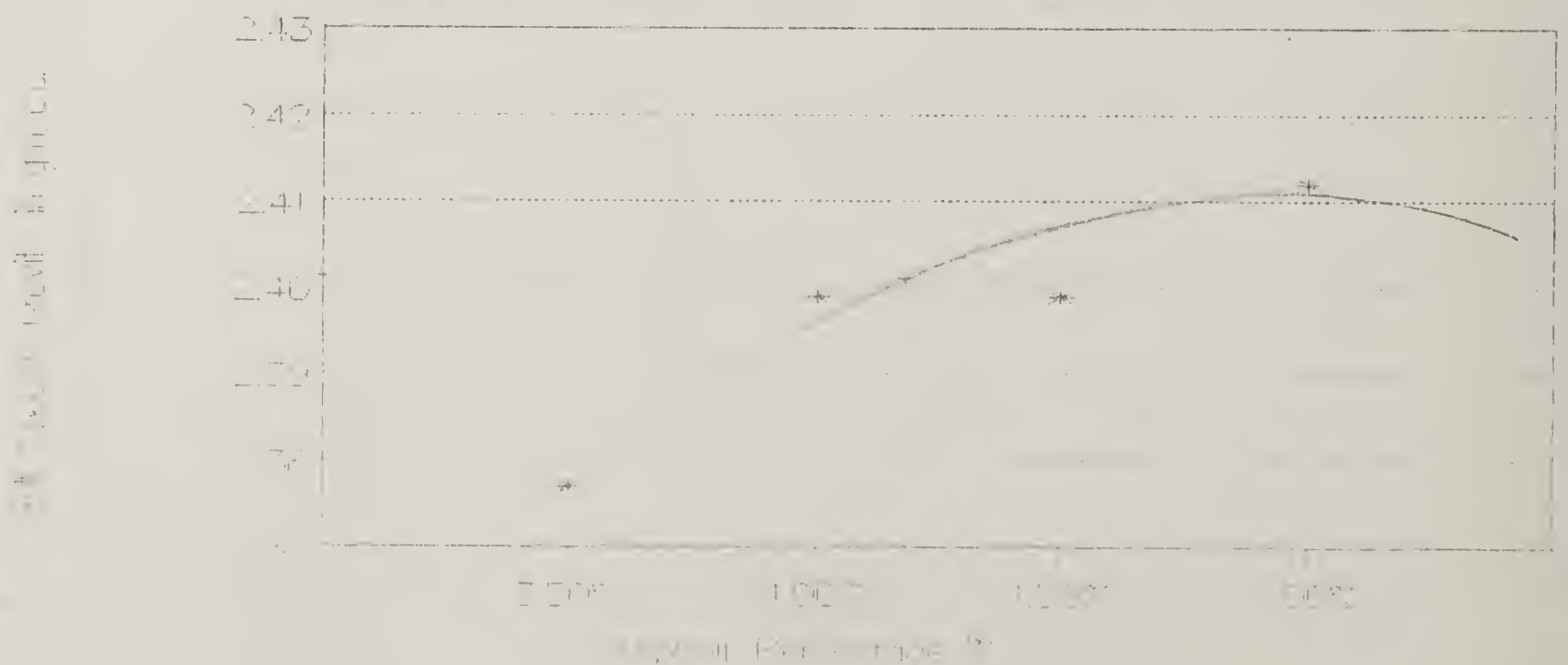
# Unmodified Conoco - II Gradation Agg.

Air Void Ratio in % (75-Blow).



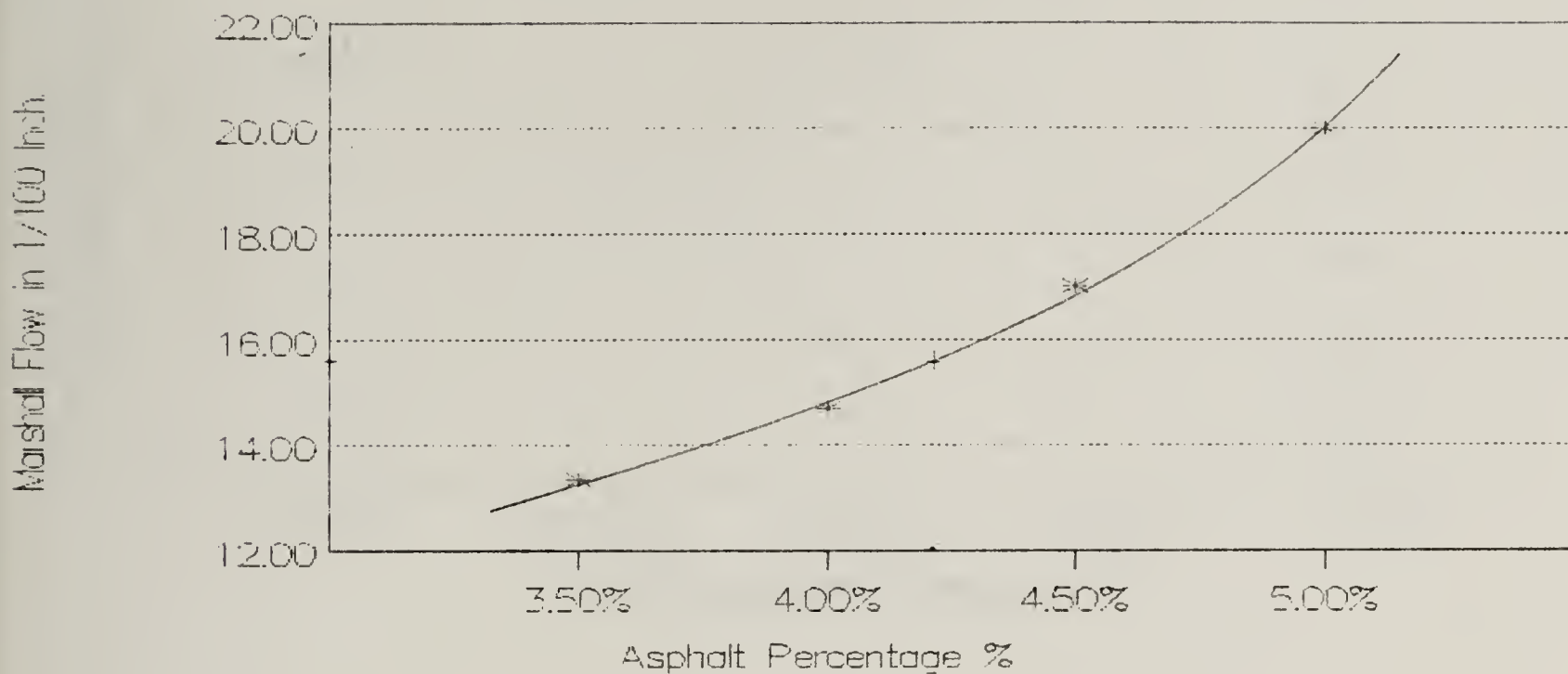
# Unmodified Conoco - II Gradation Agg.

Bulk Specific Gravity (75-Blow).



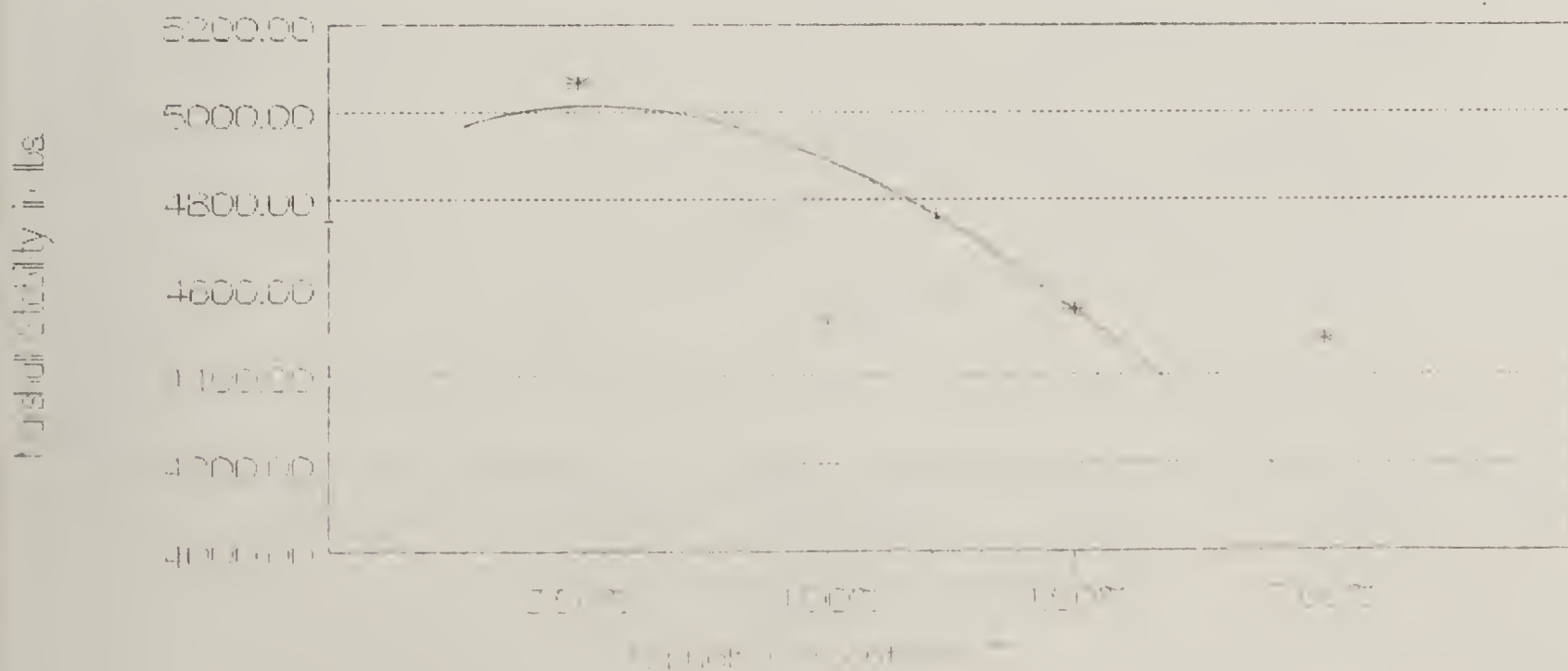
# Kraton Mod. Conoco - II Gradation Agg.

Marshall Flow in 1/100 Inch (75-Blow).



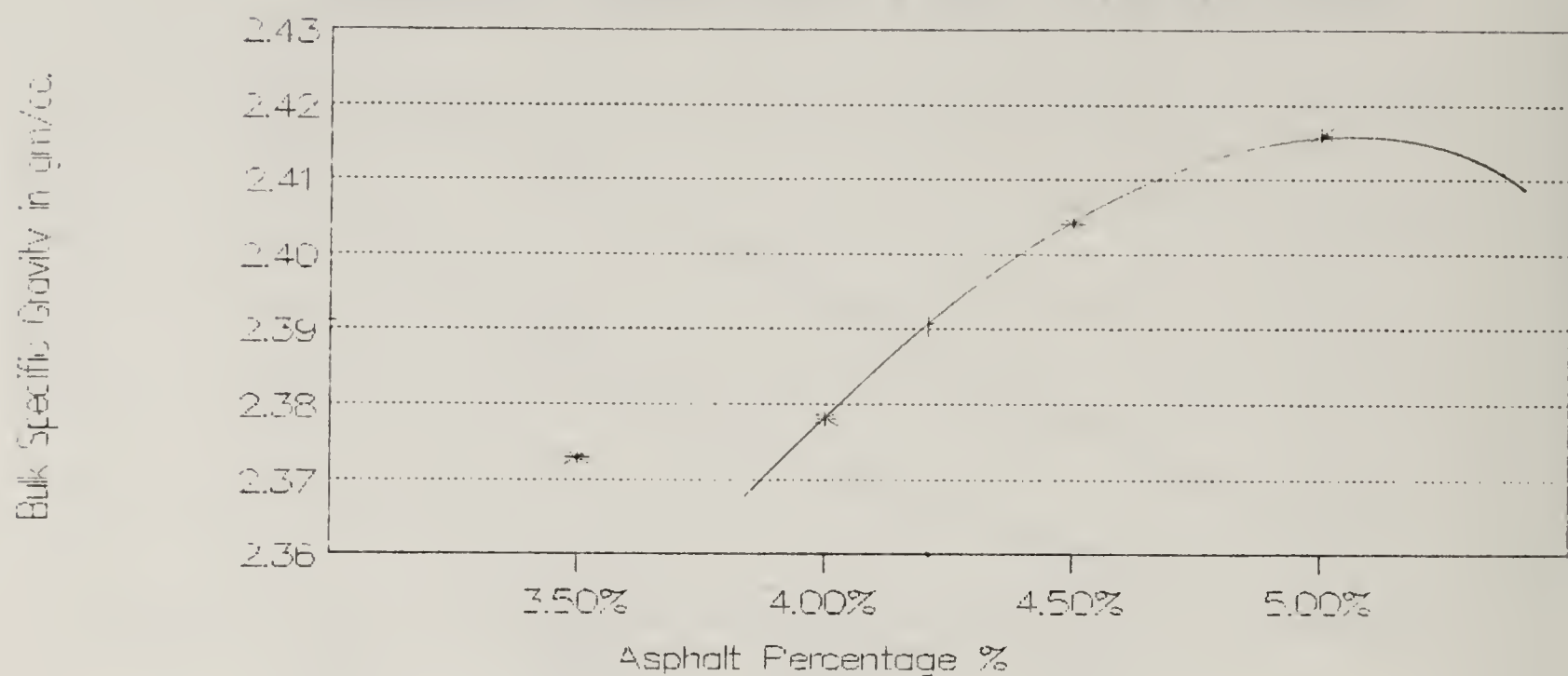
# Kraton Mod. Conoco - II Gradation Agg.

Marshall Stability in lbs. (75-Blow).



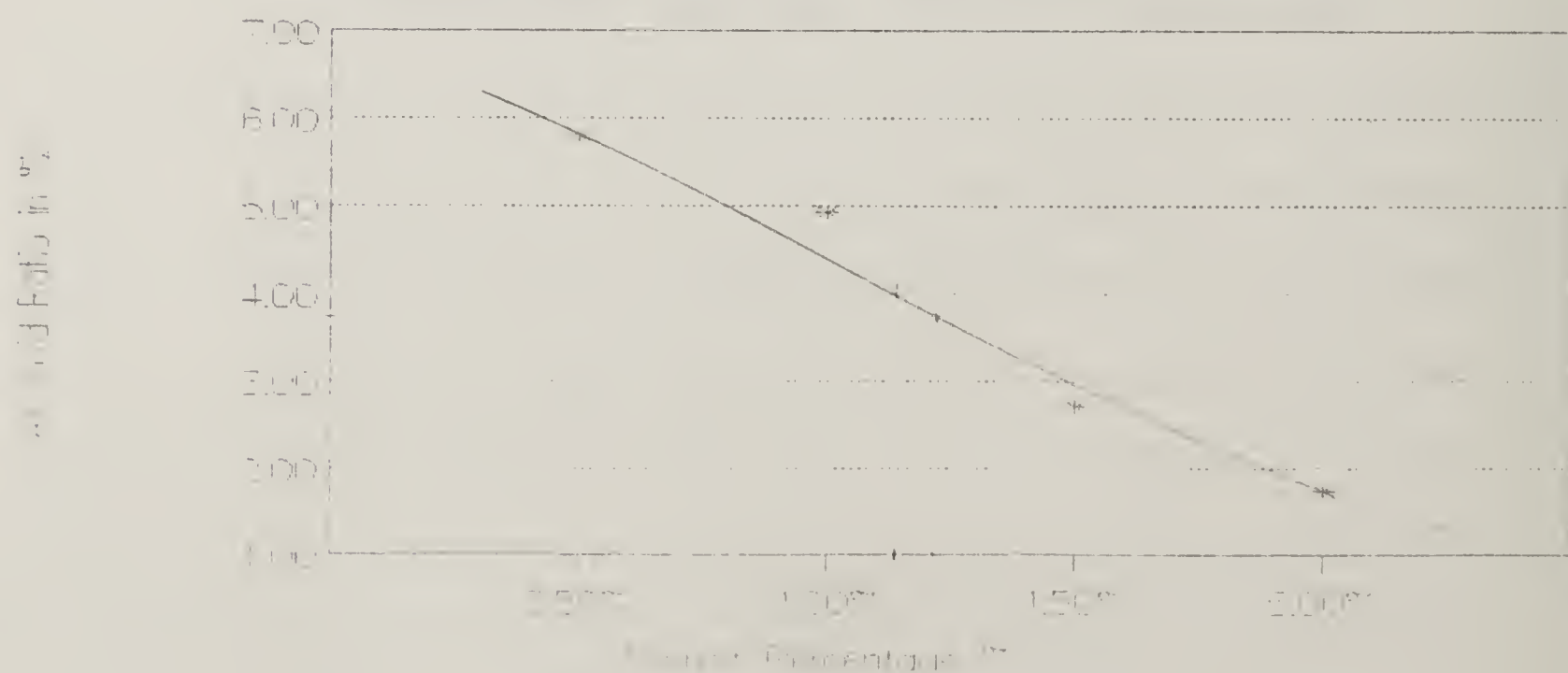
# Kraton Mod. Conoco — II Gradation Agg.

## Bulk Specific Gravity (75-Blow).



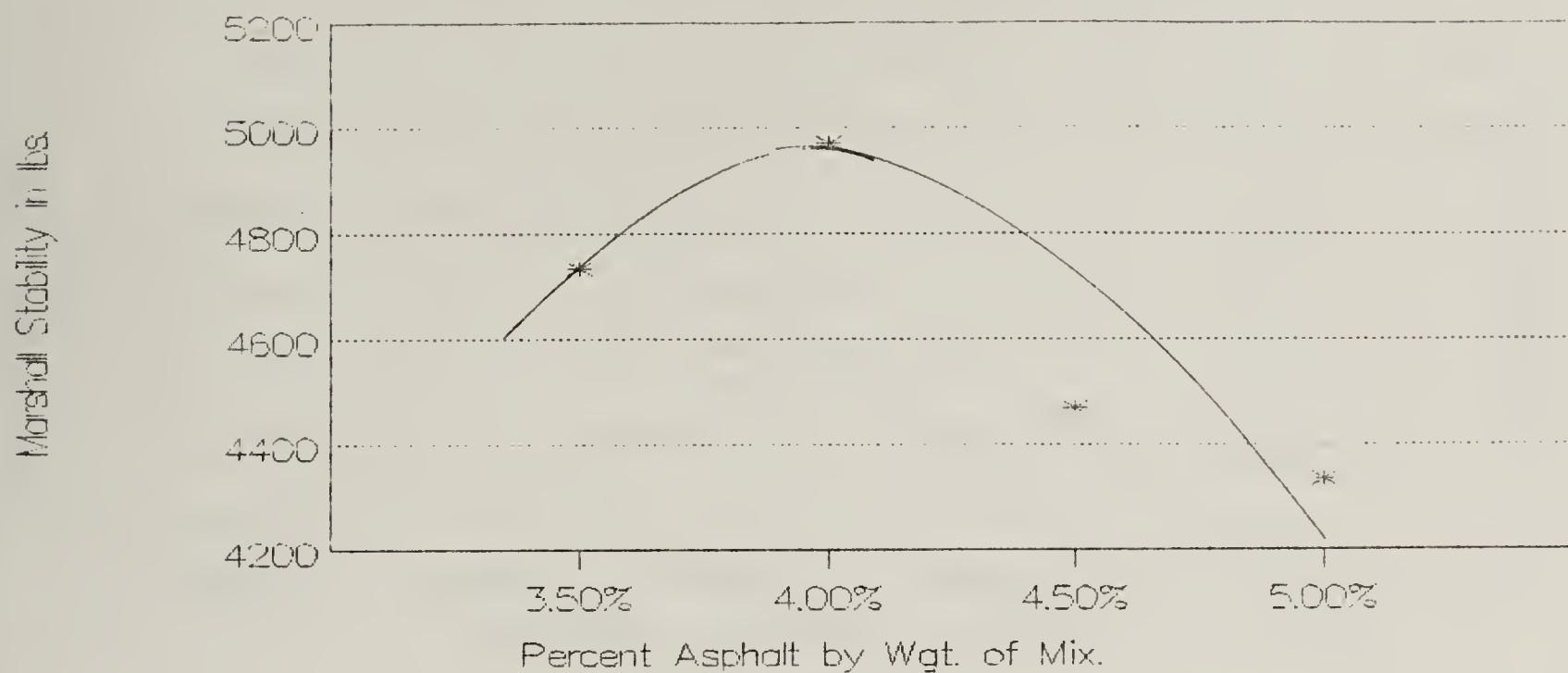
# Kraton Mod. Conoco — II Gradation Agg.

## Air Void Ratio in % (75-Blow).



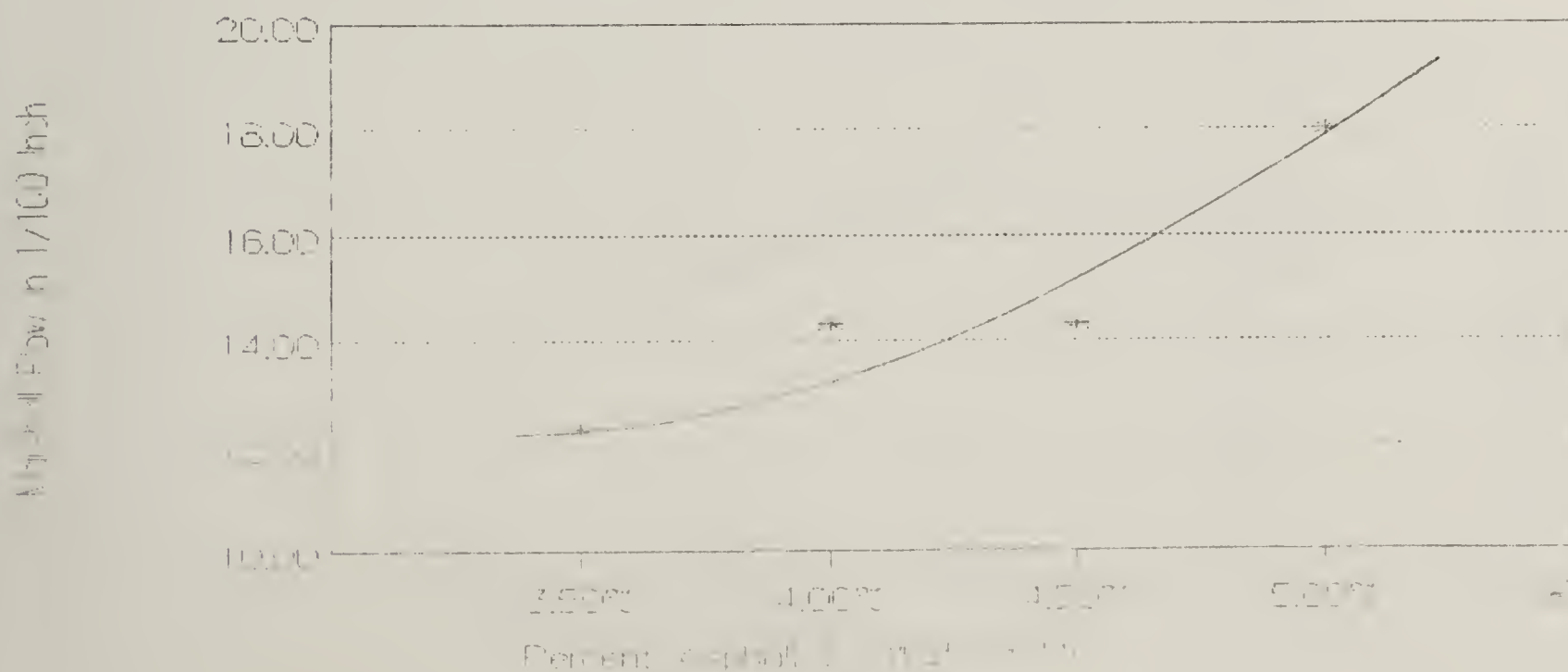
# Polybilt Mod. Conoco - II Gradation Agg

75 Blow - Marshall Stability in lbs.



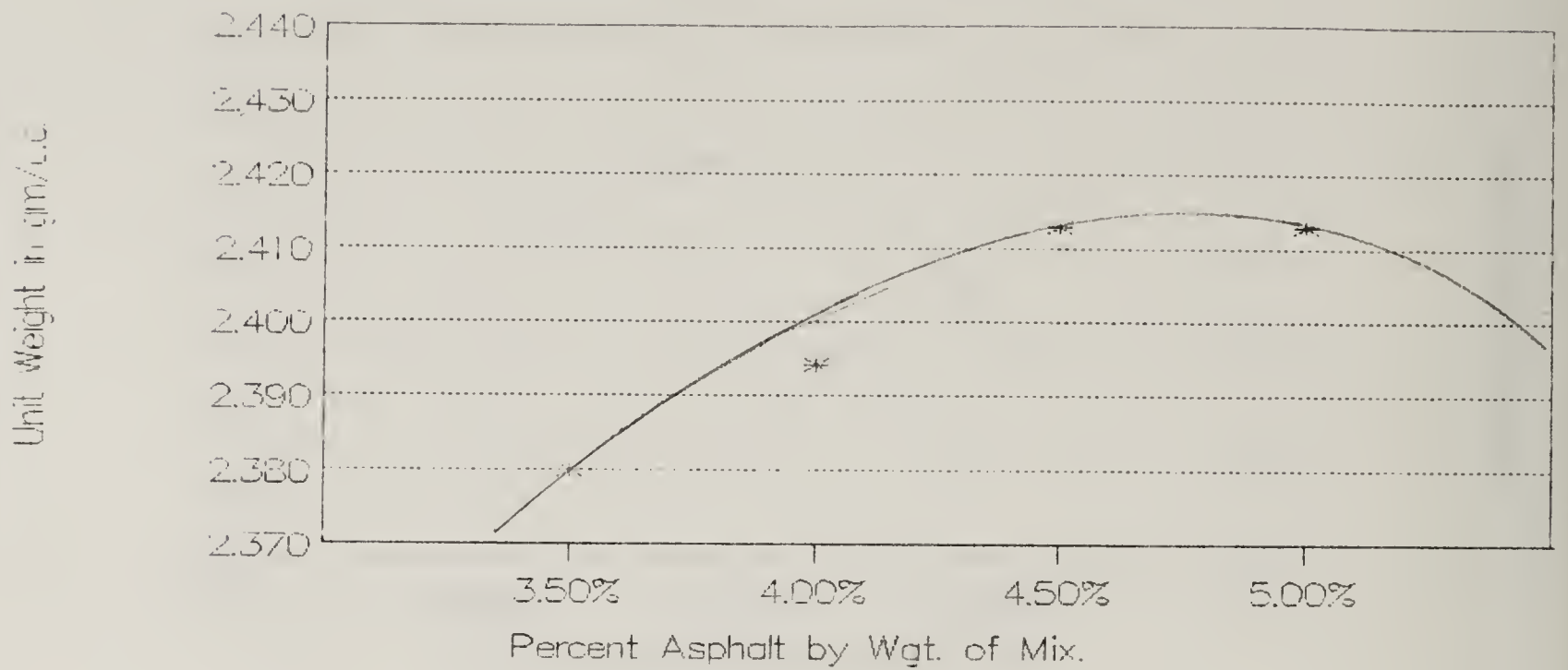
# Polybilt Mod. Conoco - II Gradation Agg

75 Blow - Marshall Flow in 1/100 Inch.



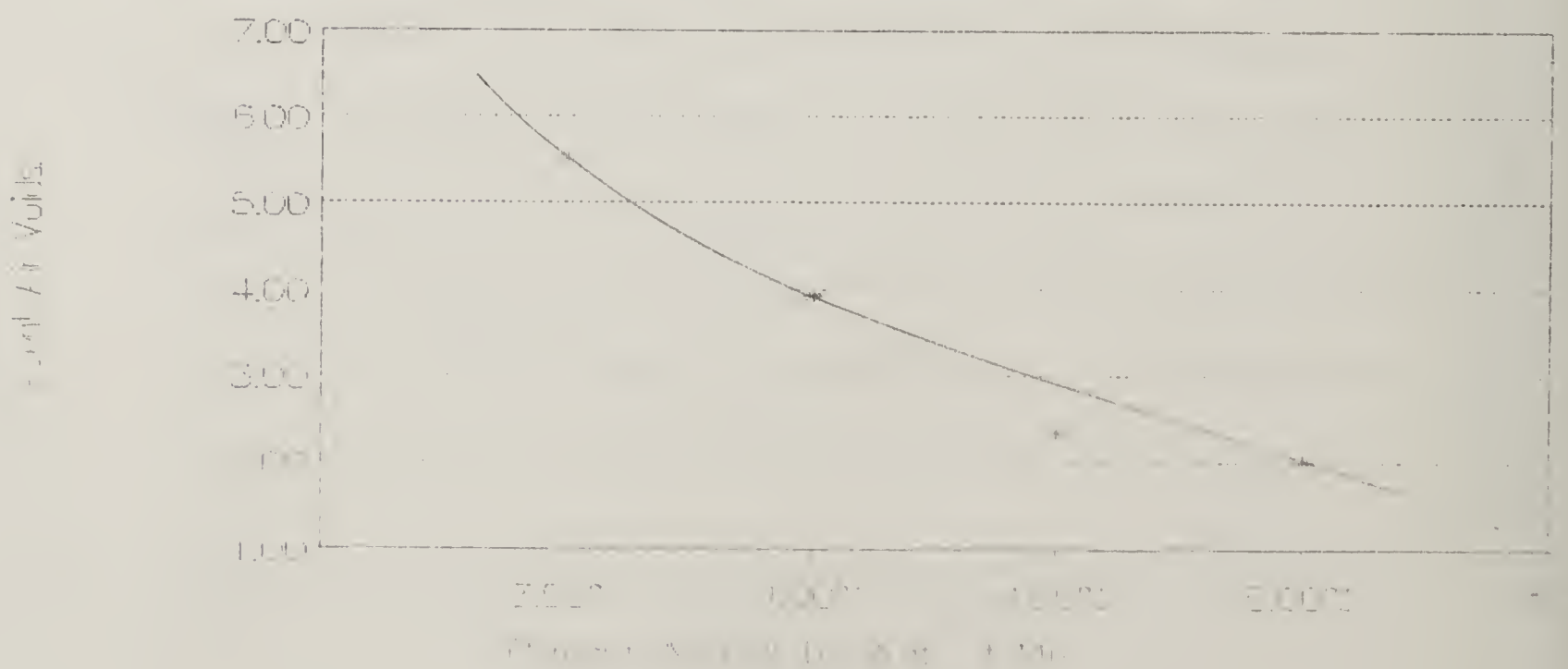
# Polybilt Mod. Conoco - II Gradation Agg

75 Blow - Unit weight in gm/c.c.



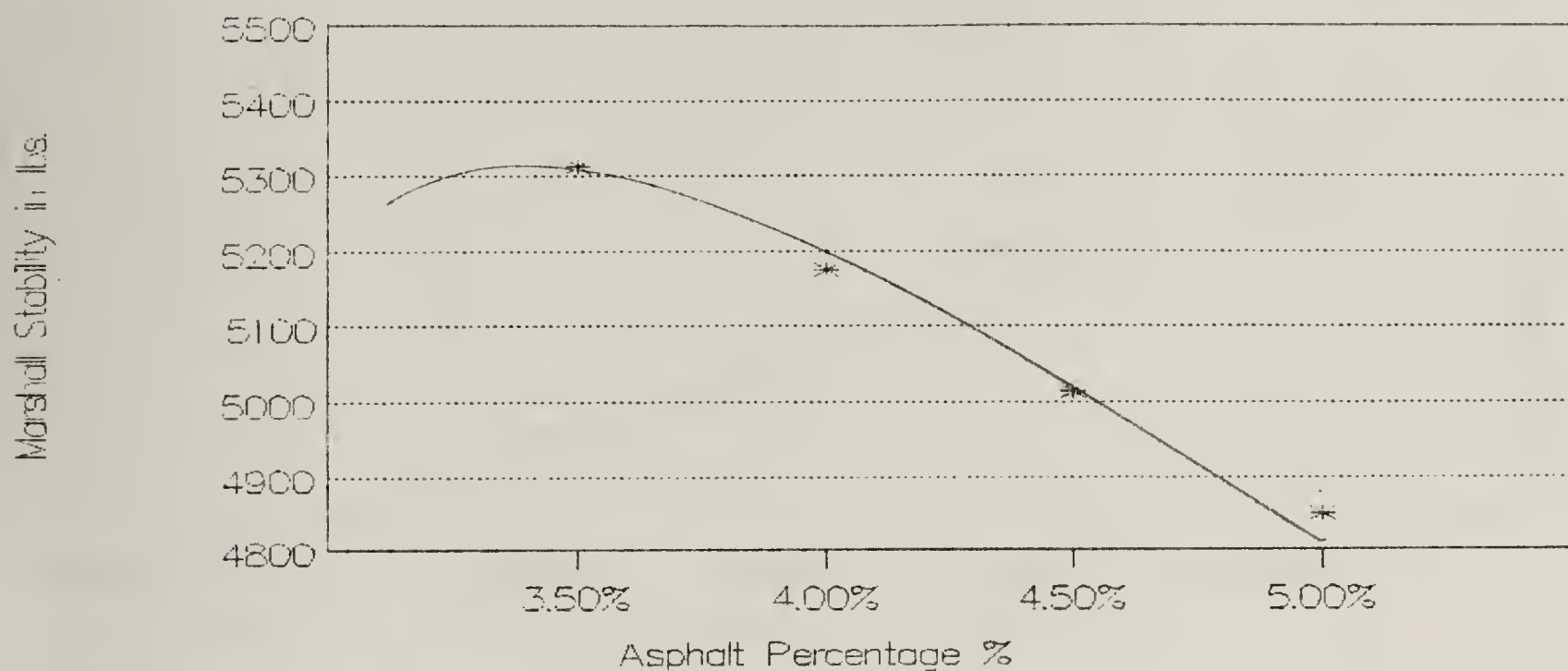
# Polybilt Mod. Conoco - II Gradation Agg

75 Blow - Percent Air Voids.



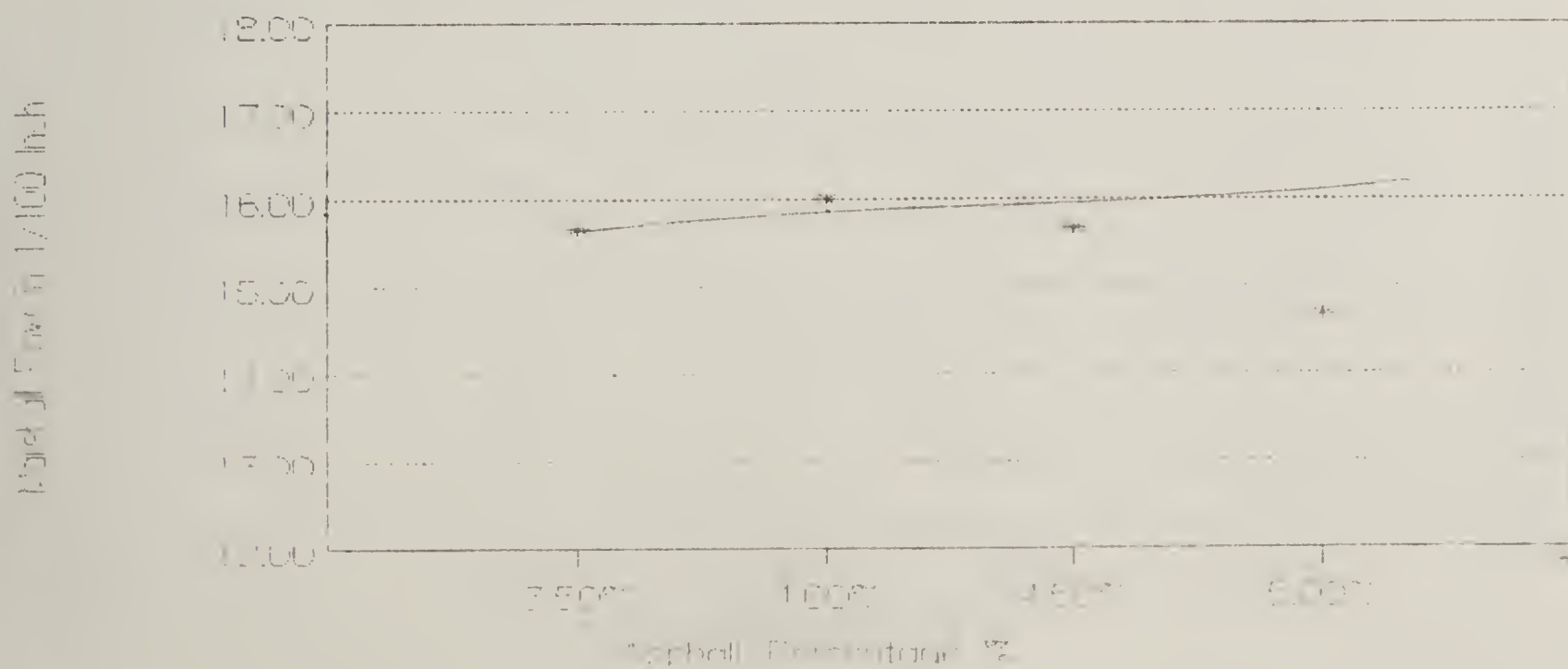
## Unmodified Conoco - II Gradation Agg.

112 Blows - Marshall Stability in lbs.



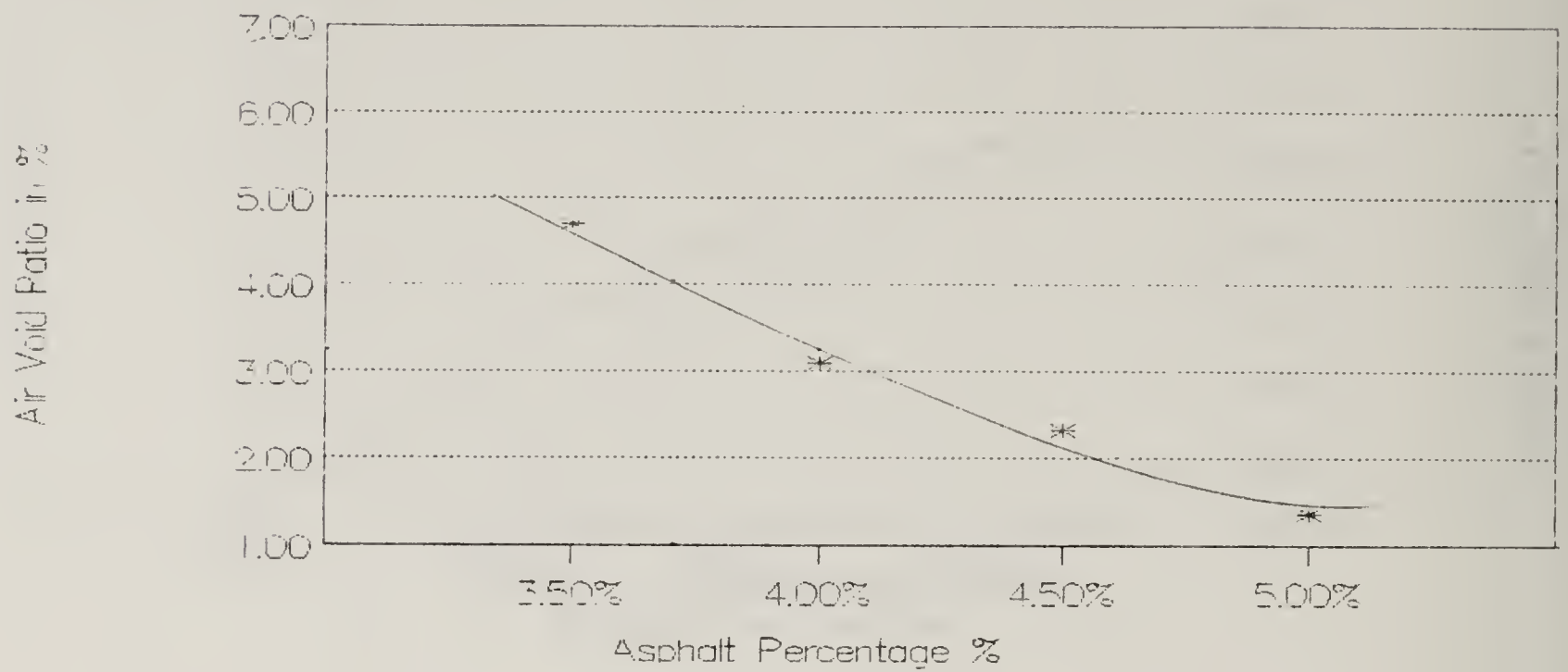
## Unmodified Conoco - II Gradation Agg.

112 Blows - Marshall Flow in 1/100 Inch



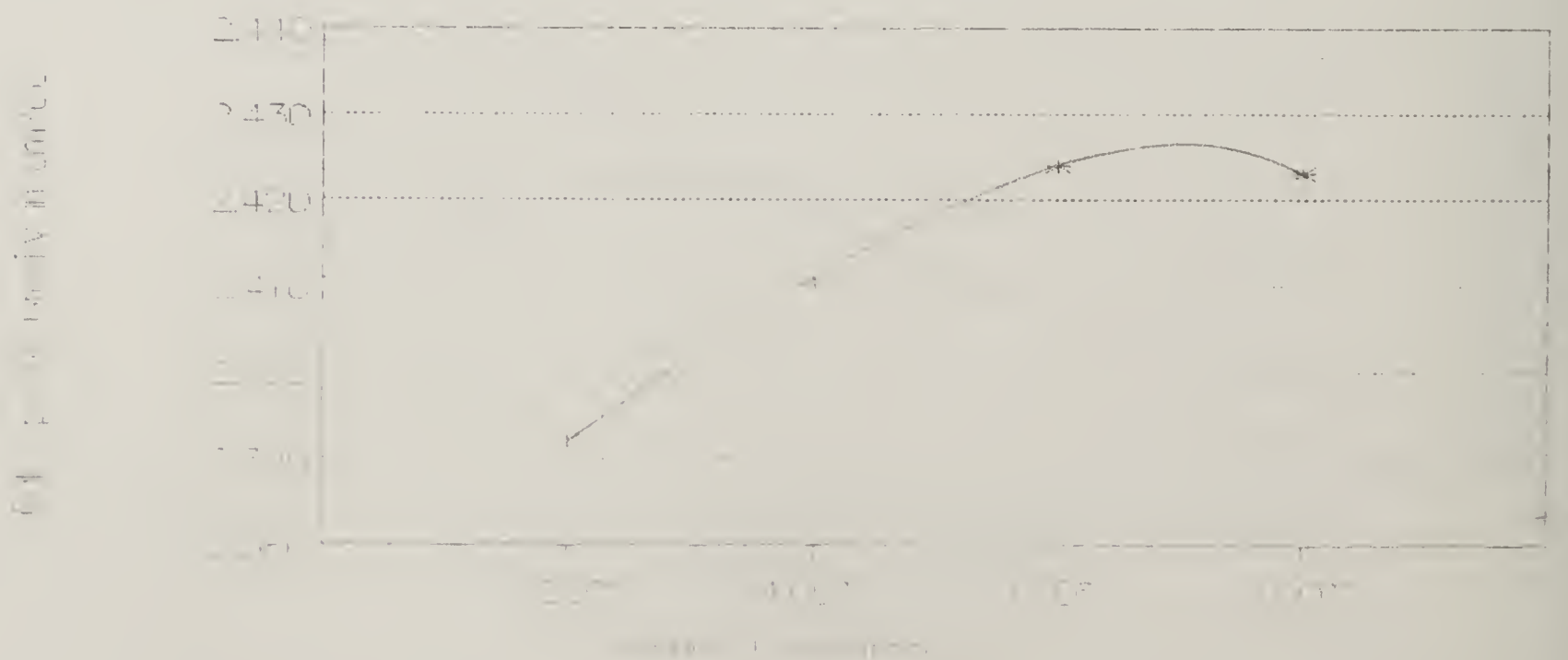
# Unmodified Conoco - II Gradation Agg.

112 Blows - Air Void Ratio in %



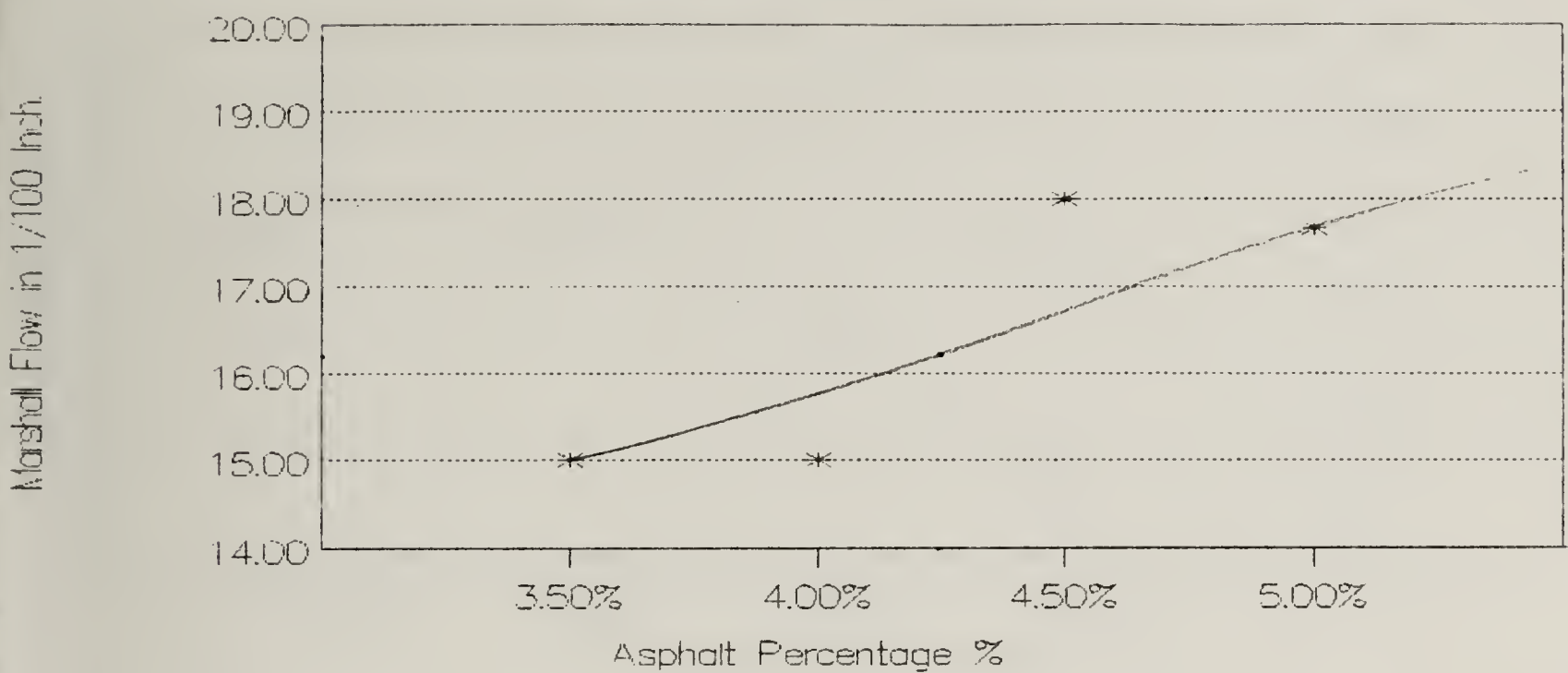
# Unmodified Conoco - II Gradation Agg.

112 Blows - Bulk Specific Gravity



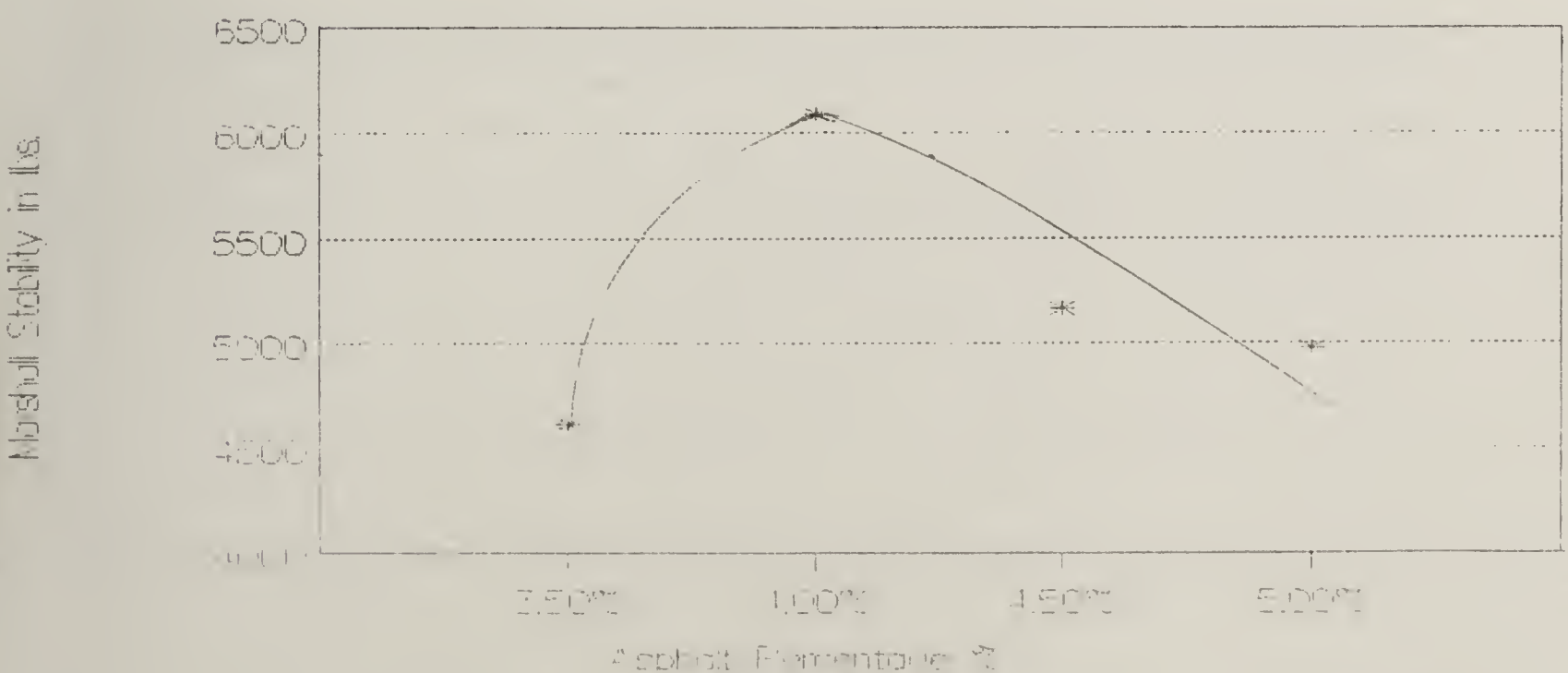
Kraton Mod. Conoco — II Gradation Agg.

112 Blows — Marshall Flow in 1/100 Inch



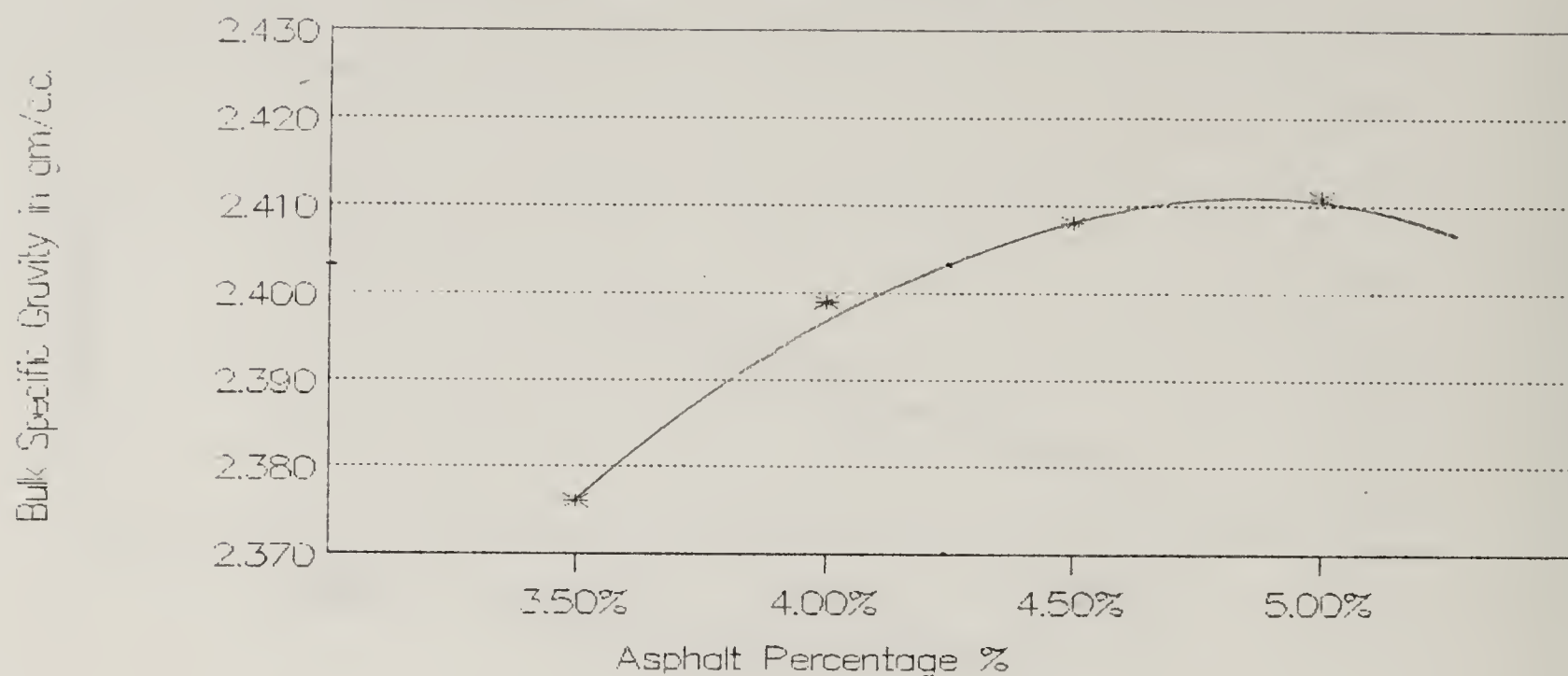
Kraton Mod. Conoco — II Gradation Agg.

112 Blows — Marshall Stability in lbs.



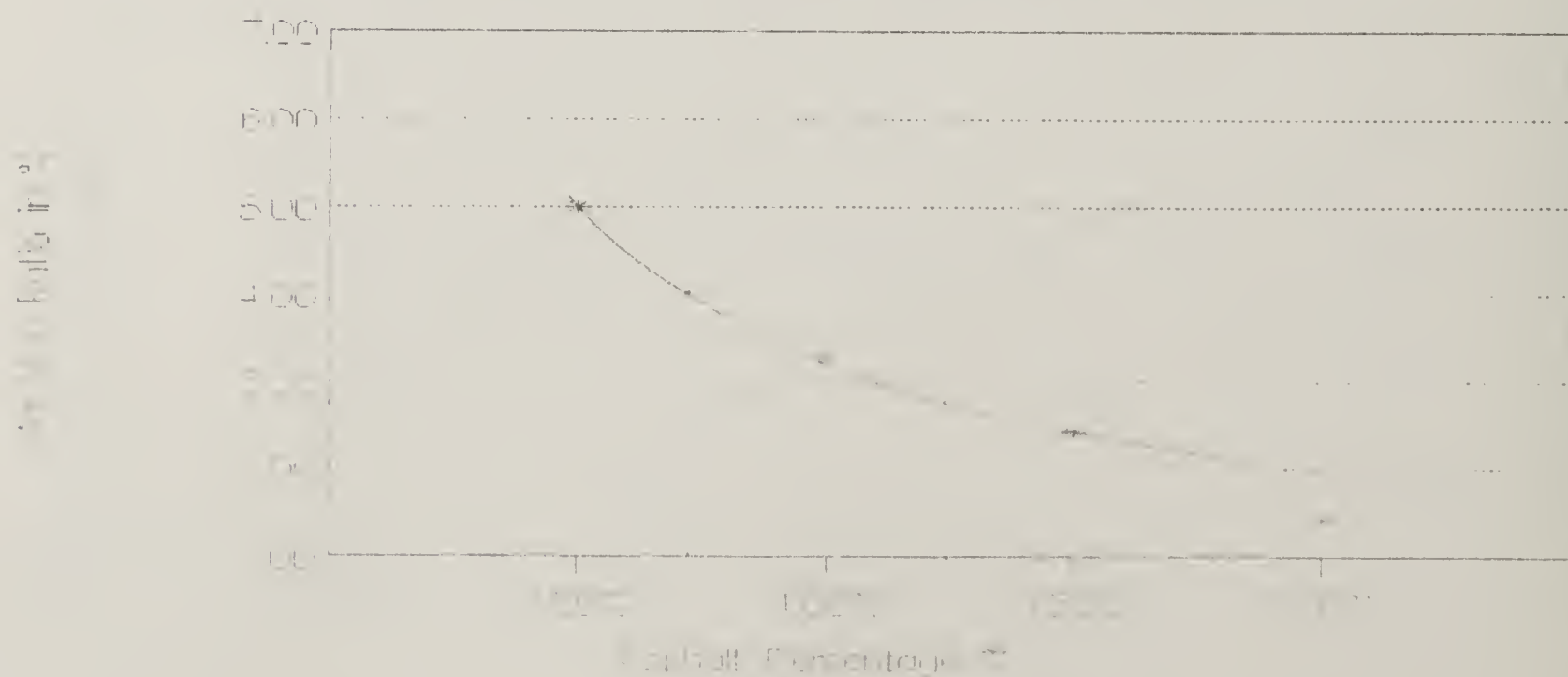
# Kraton Mod. Conoco — II Gradation Agg.

## 112 Blows — Bulk Specific Gravity



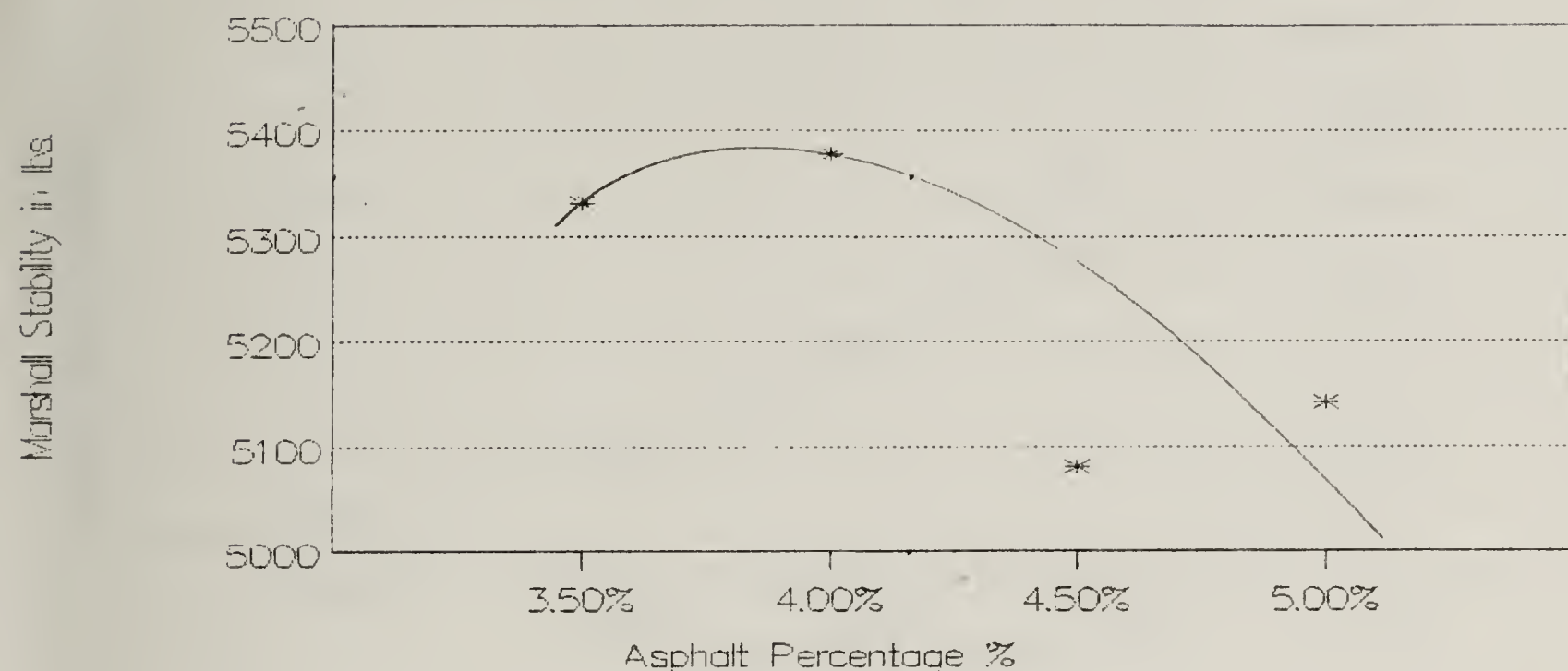
# Kraton Mod. Conoco — II Gradation Agg.

## 112 Blows — Air Void Ratio in %



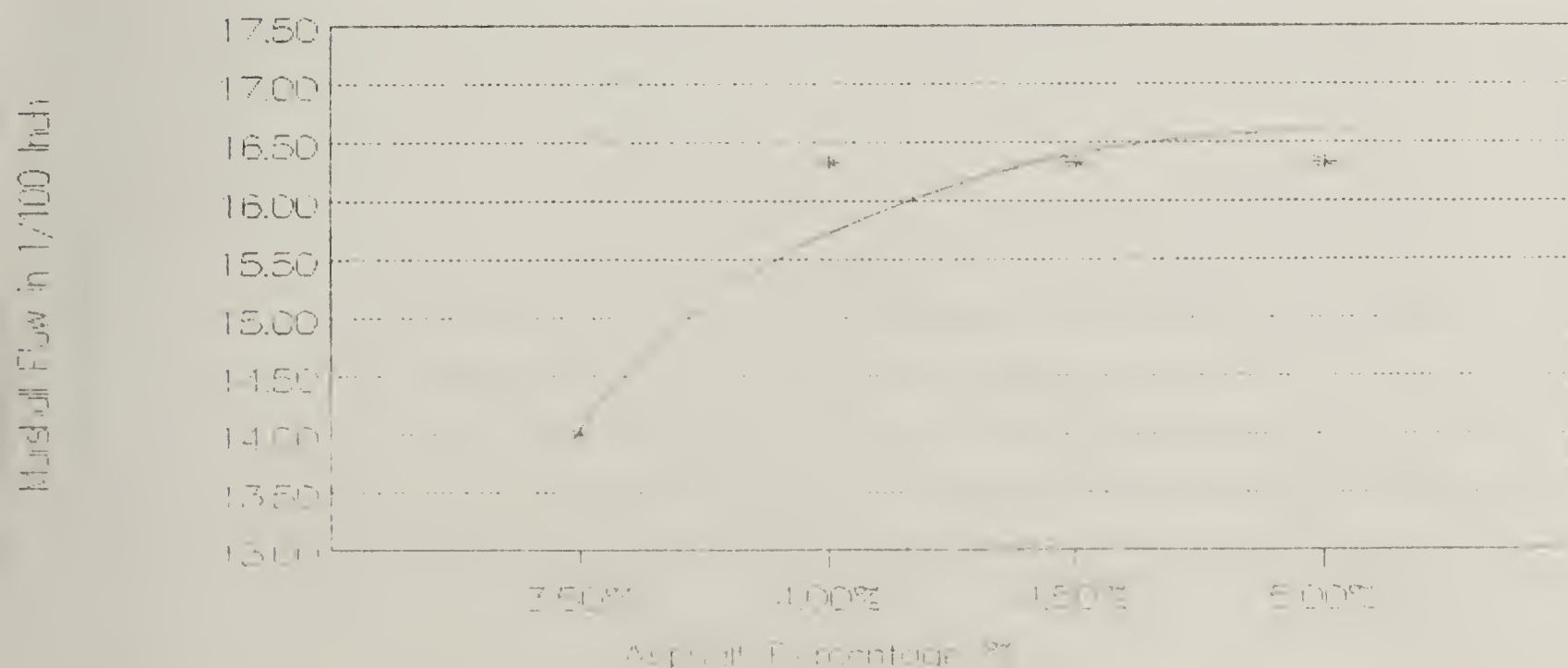
# Polybilt Mod. Conoco- II Gradation Agg.

112 Blows - Marshall Stability in lbs.



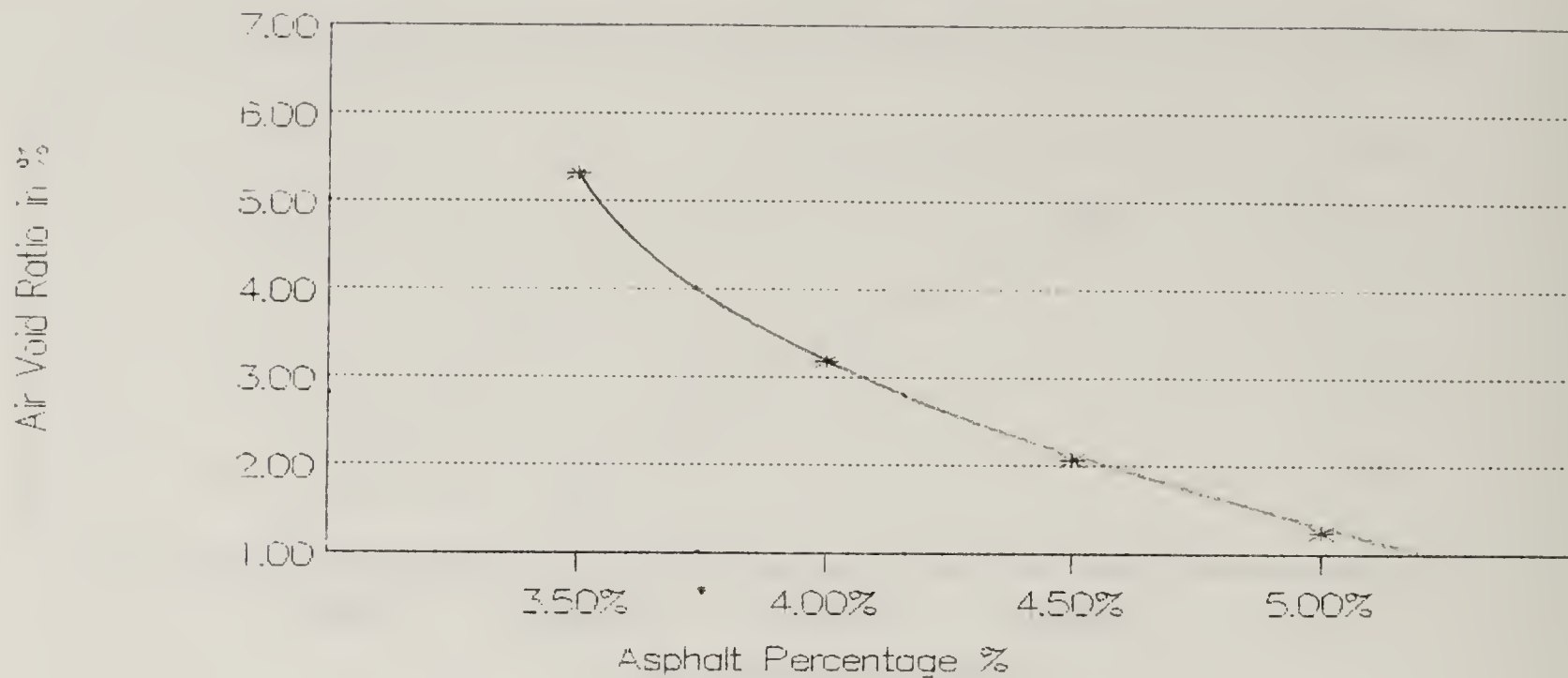
# Polybilt Mod. Conoco- II Gradation Agg.

112 Blows - Marshall Flow in 1/100 Inch



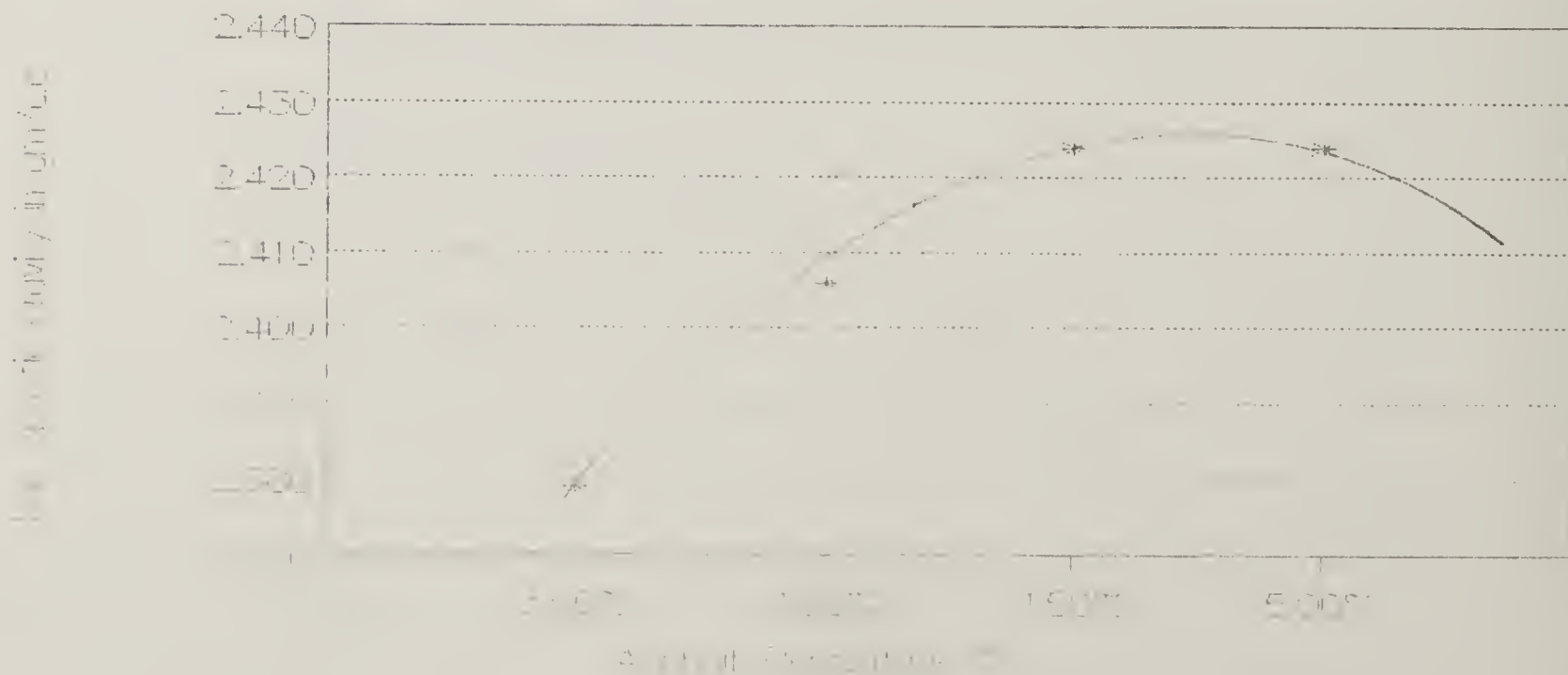
# Polybilt Mod. Conoco— II Gradation Agg.

112 Blows - Air Void Ratio in %



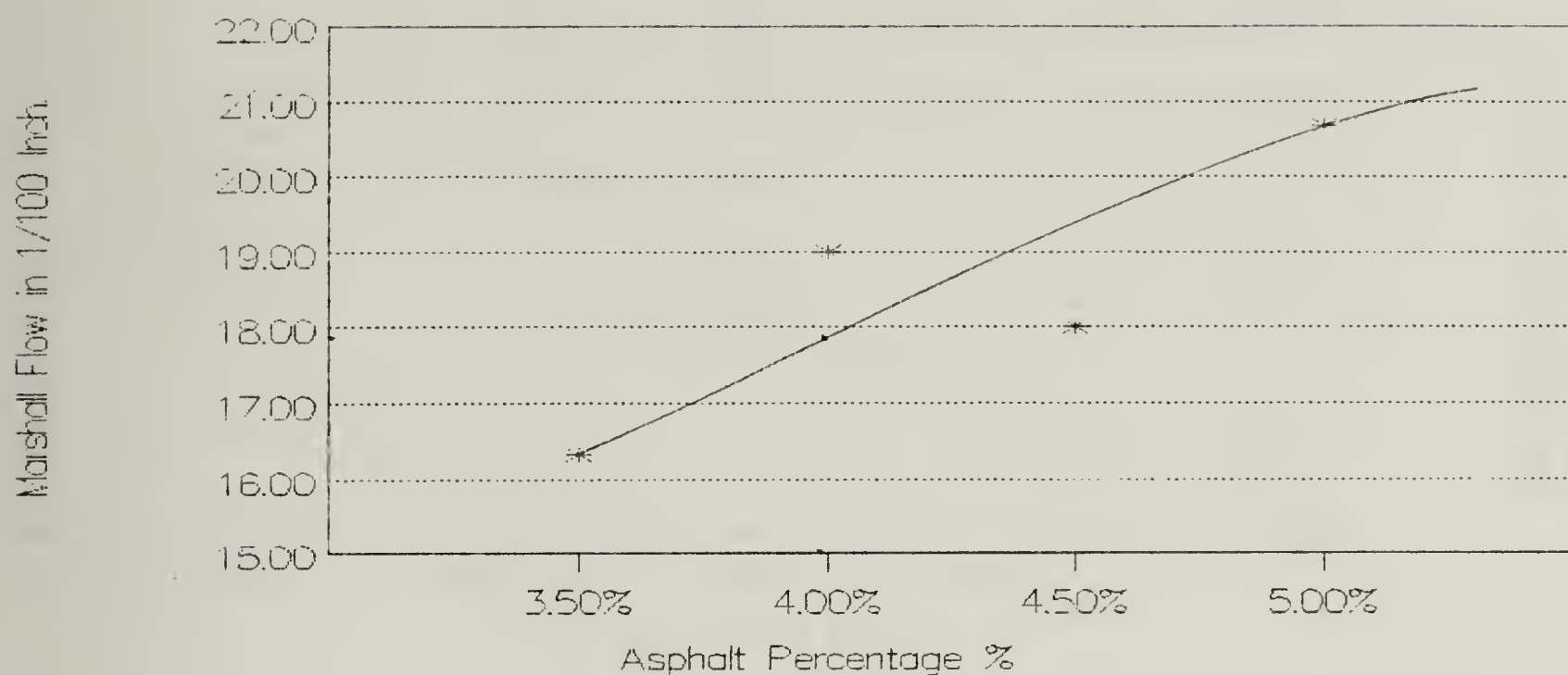
# Polybilt Mod. Conoco— II Gradation Agg.

112 Blows - Bulk Specific Gravity



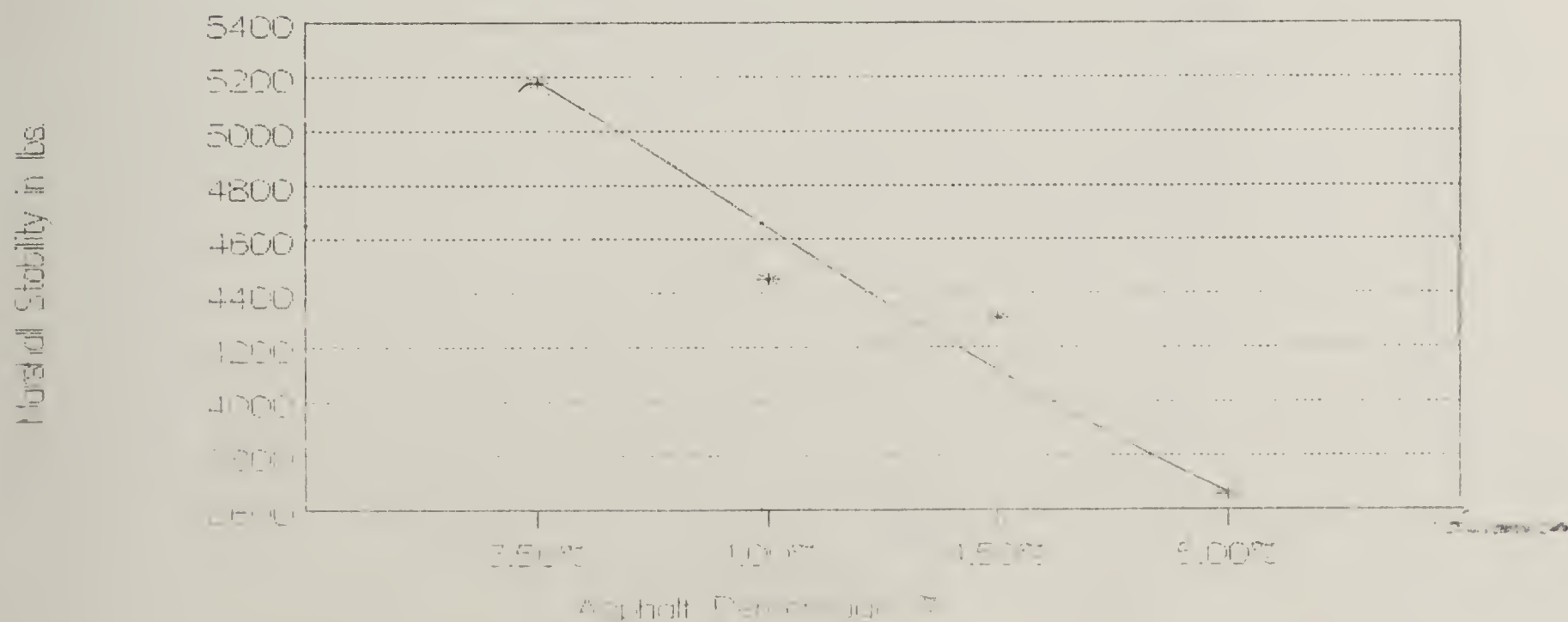
# Unmodified Conoco - II Gradation Agg.

## Mineral Filler - Marshall Flow



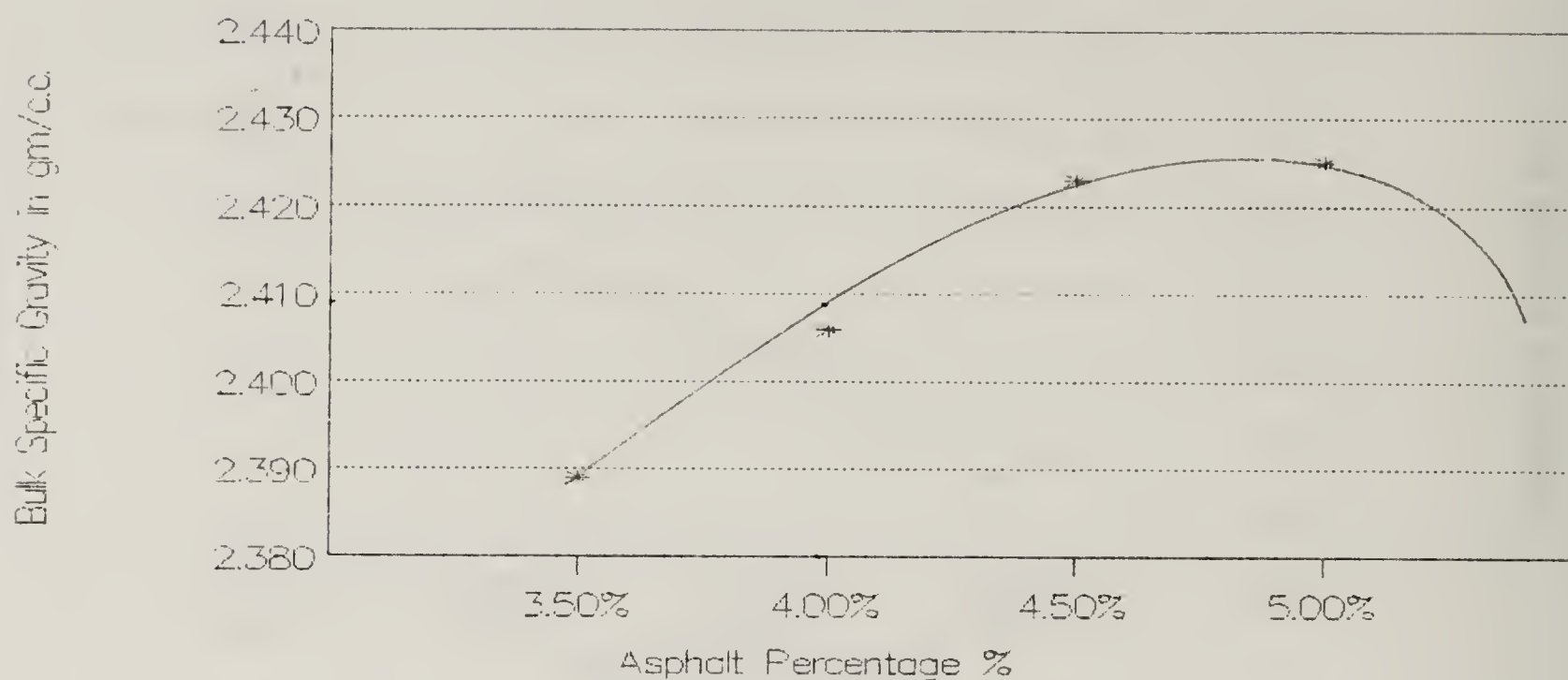
# Unmodified Conoco - II Gradation Agg.

## Mineral Filler - Marshall Stability



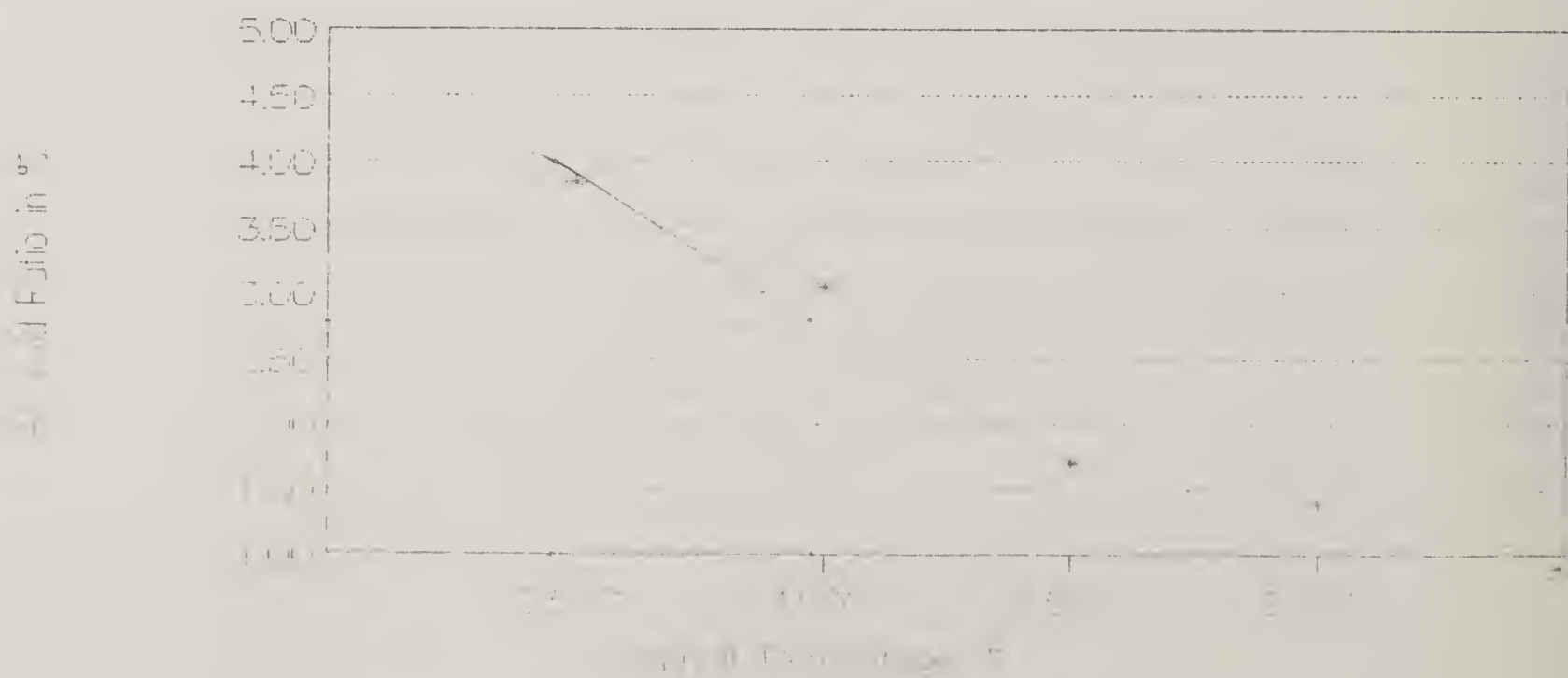
## Unmodified Conoco - II Gradation Agg.

### Mineral Filler - Bulk Specific Gravity



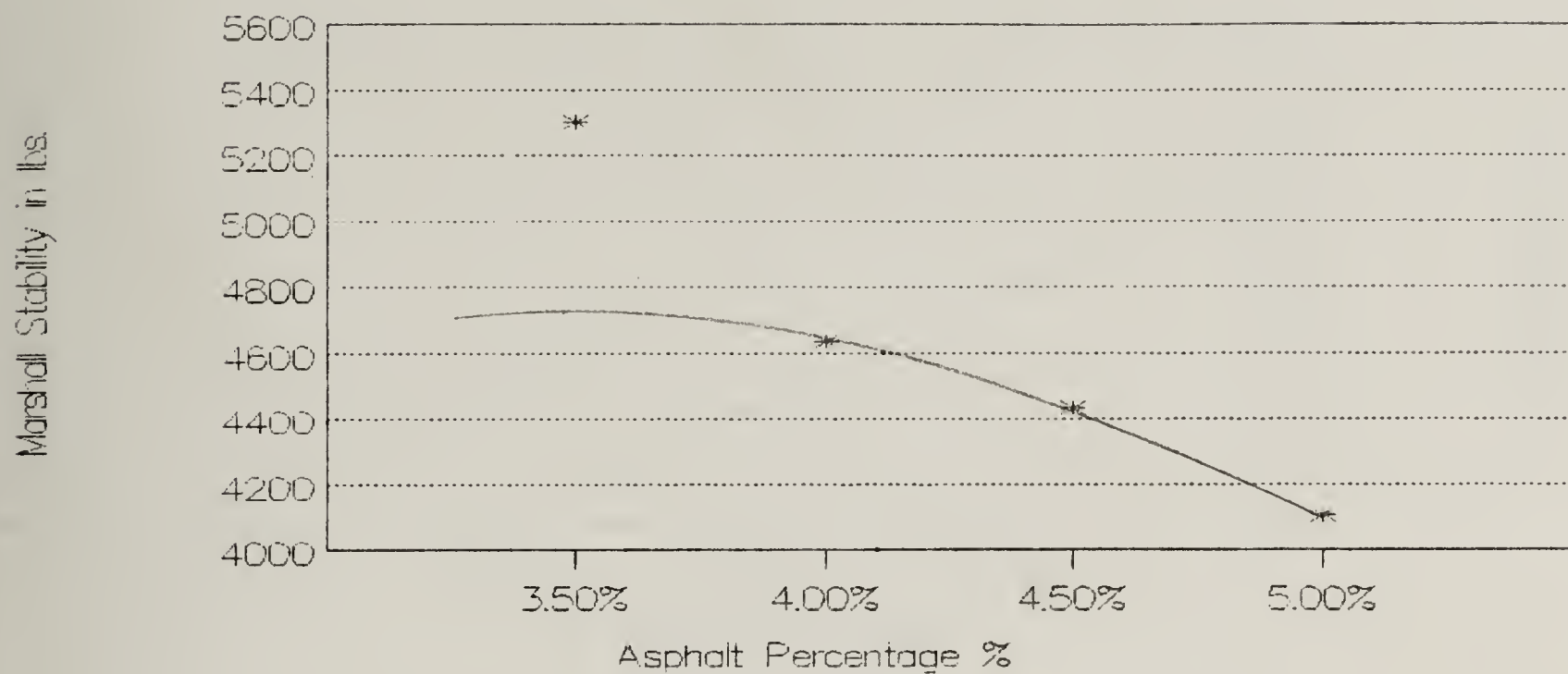
## Unmodified Conoco - II Gradation Agg.

### Mineral Filler - Air Void Ratio in %



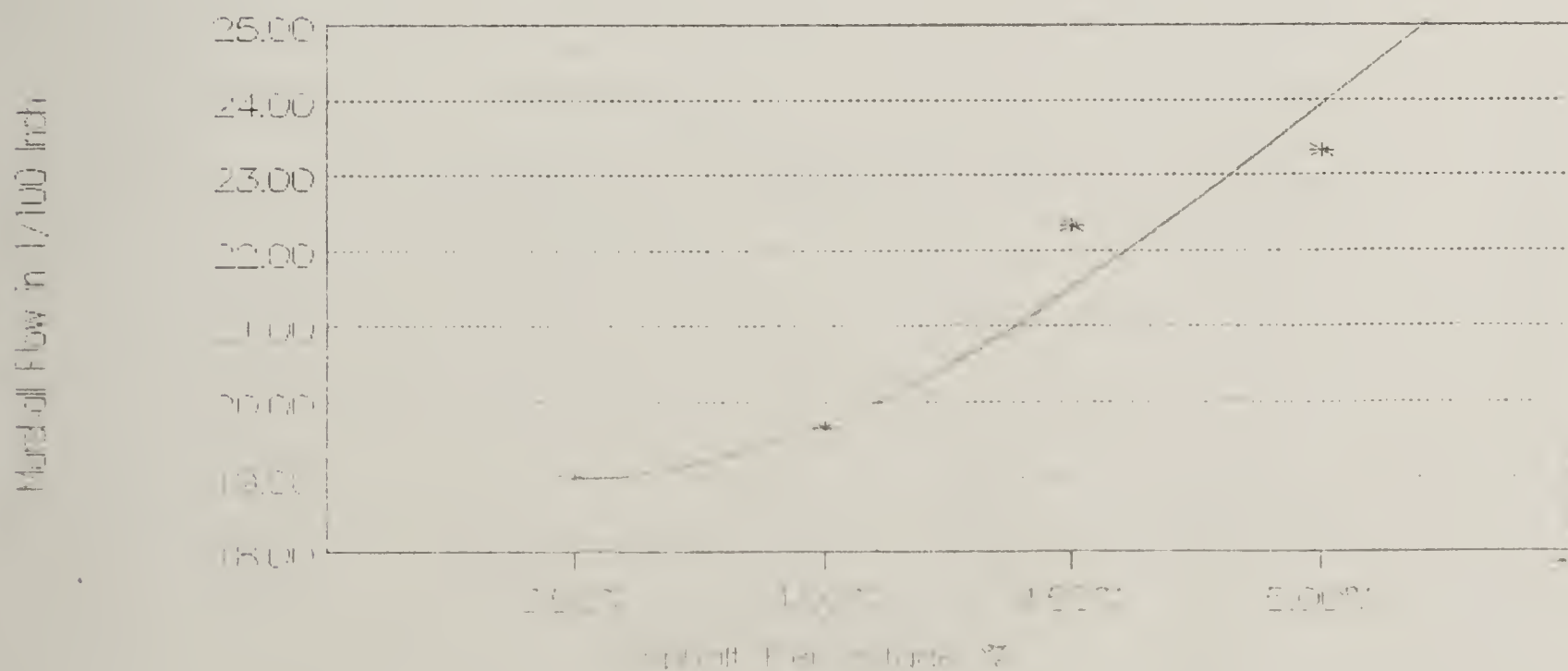
# Kraton Mod. Conoco - II Gradation Agg.

## Mineral Filler - Marshall Stability



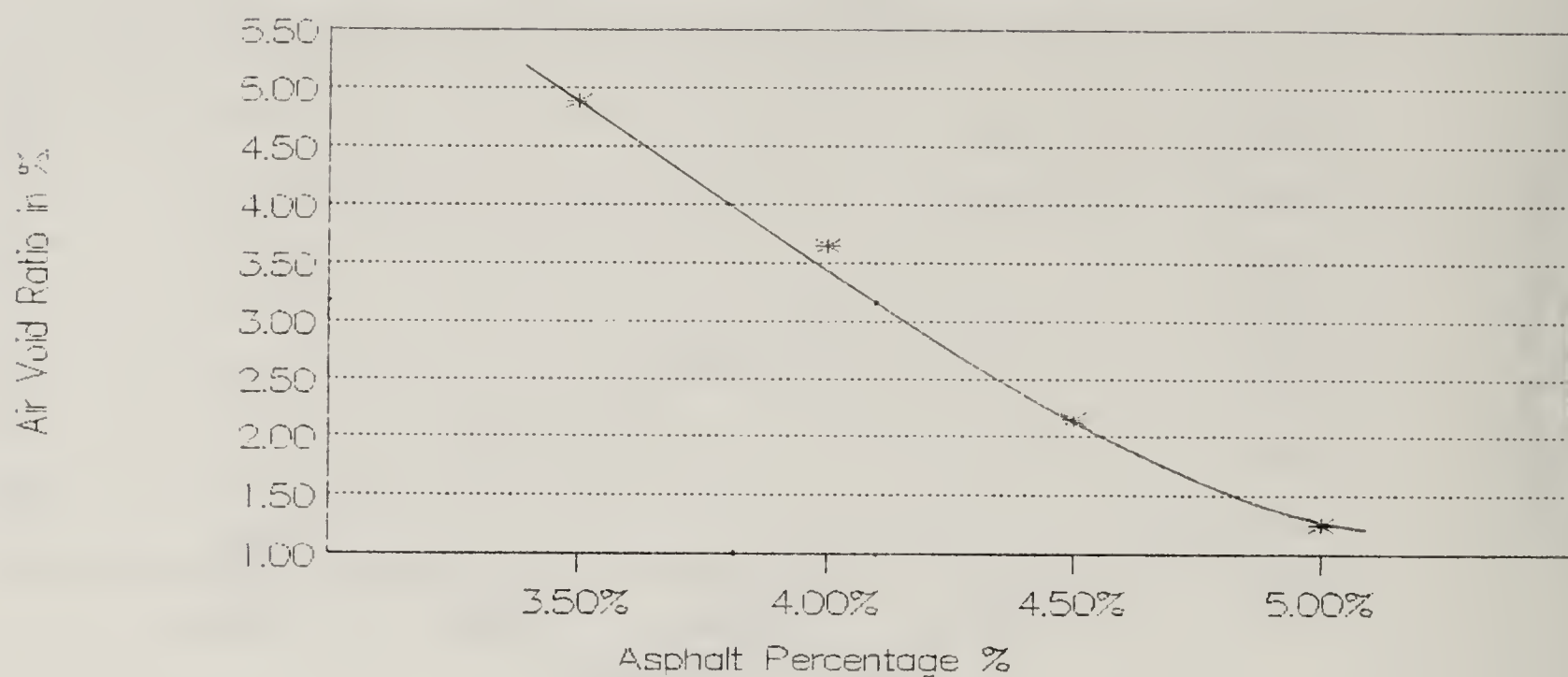
# Kraton Mod. Conoco - II Gradation Agg.

## Mineral Filler - Marshall Flow



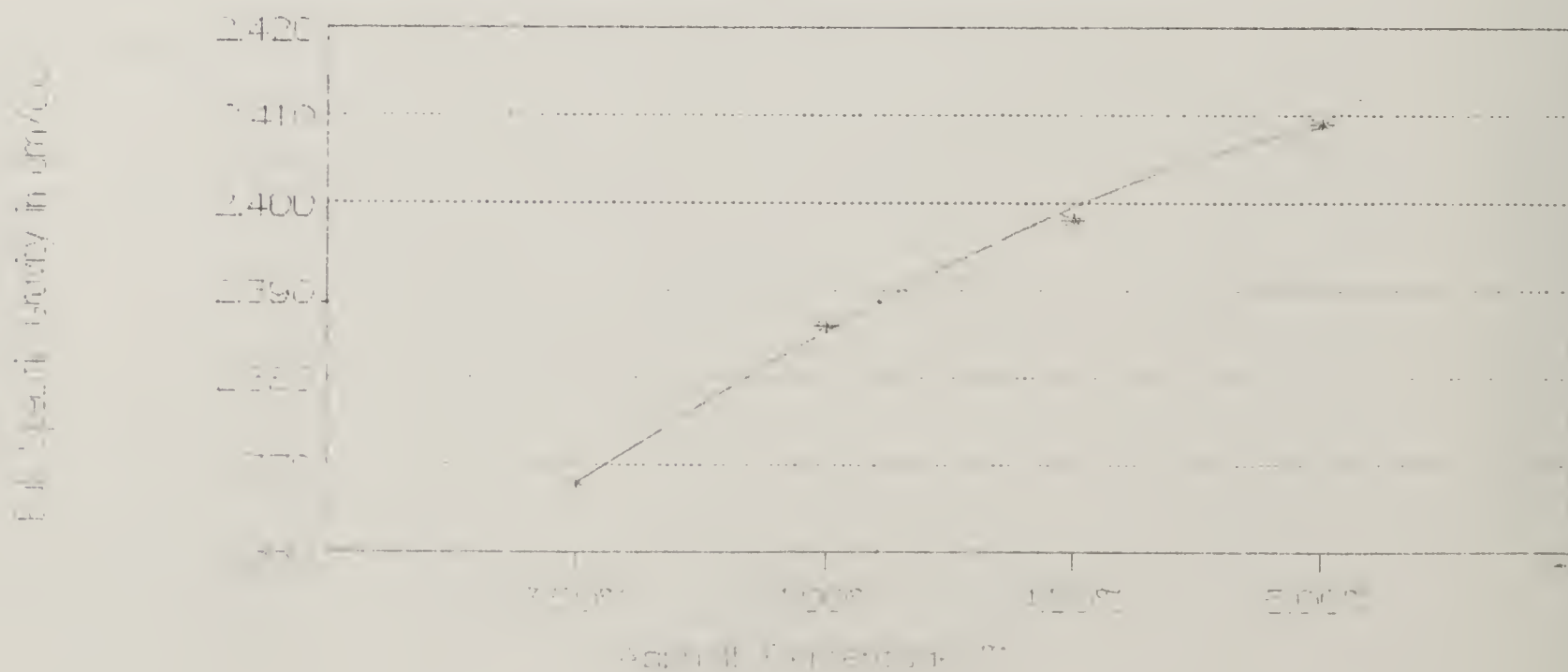
# Kraton Mod. Conoco - II Gradation Agg.

Mineral Filler - Air Void Ratio in %



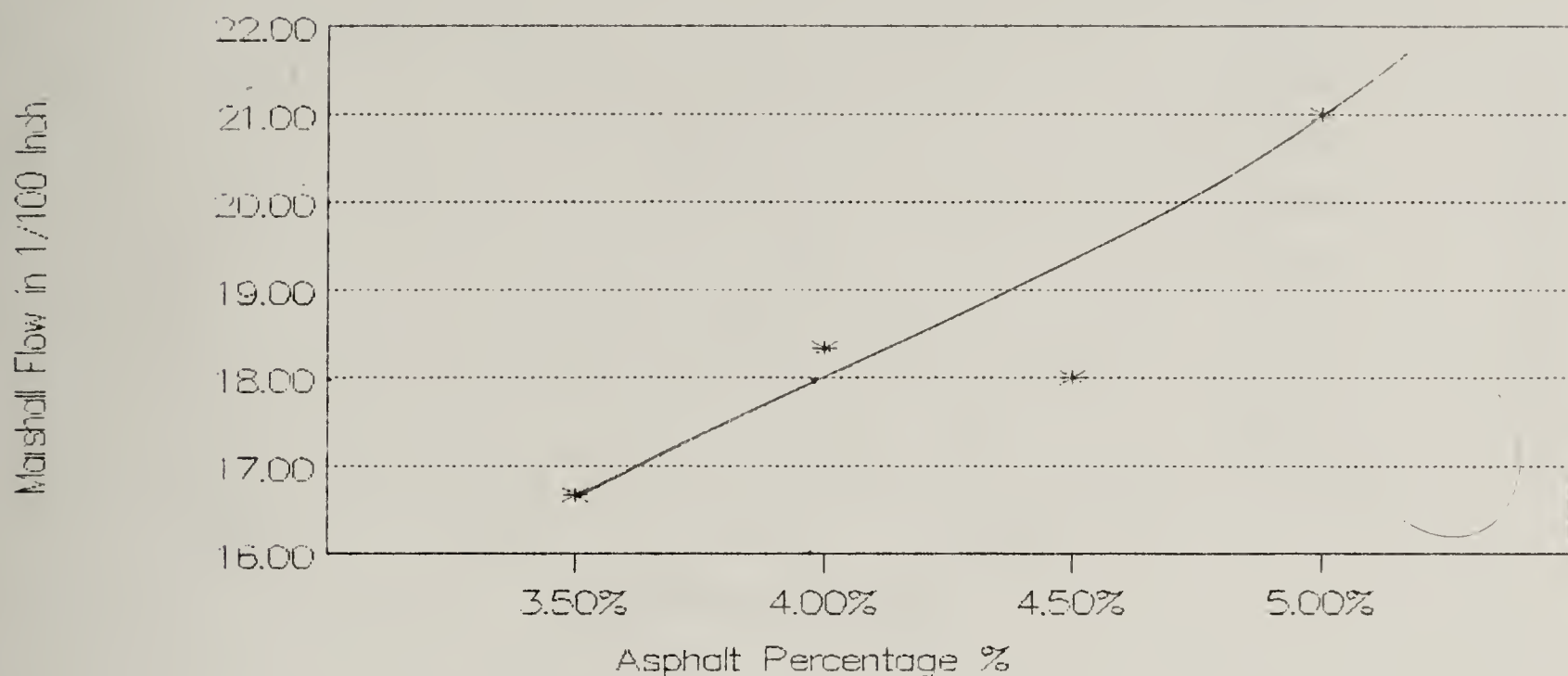
# Kraton Mod. Conoco - II Gradation Agg.

Mineral Filler - Bulk Specific Gravity



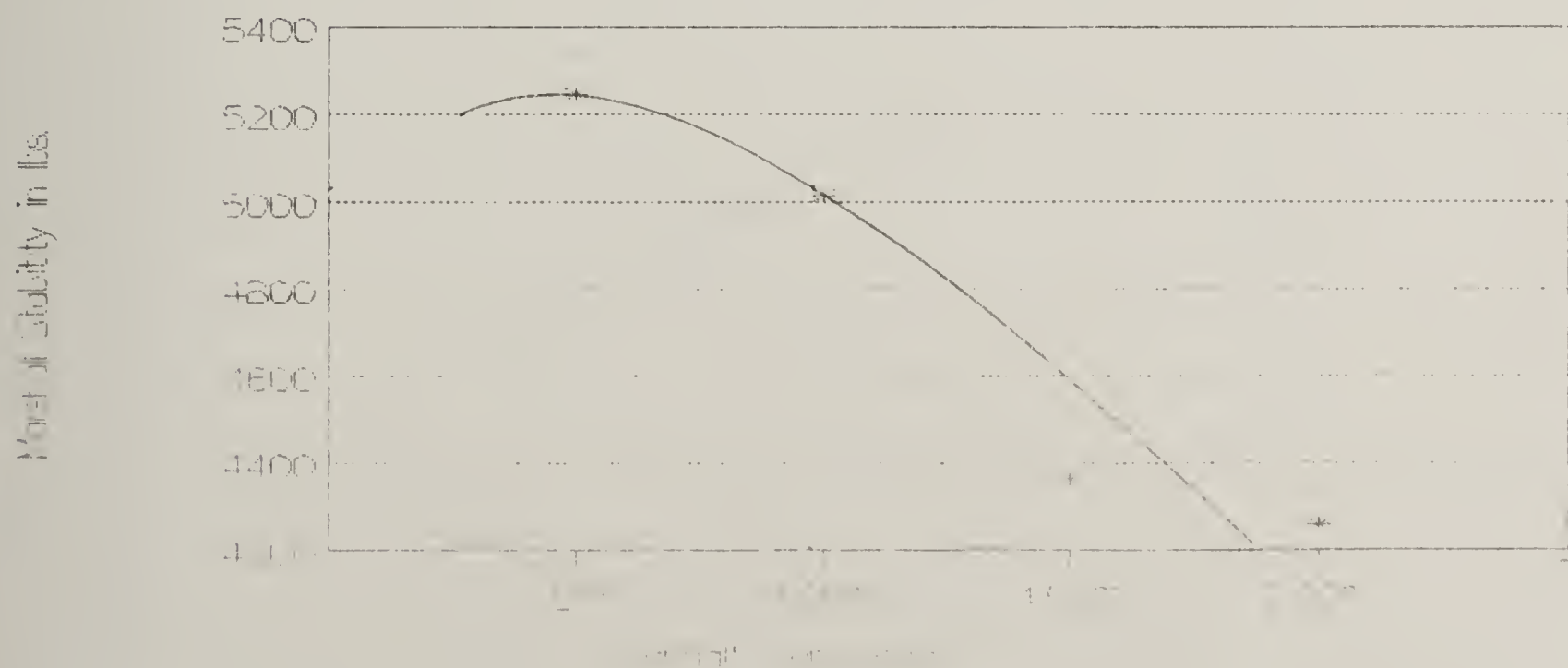
# Polybilt Mod. Conoco - II Gradation Agg

## Mineral Filler - Marshall Flow.

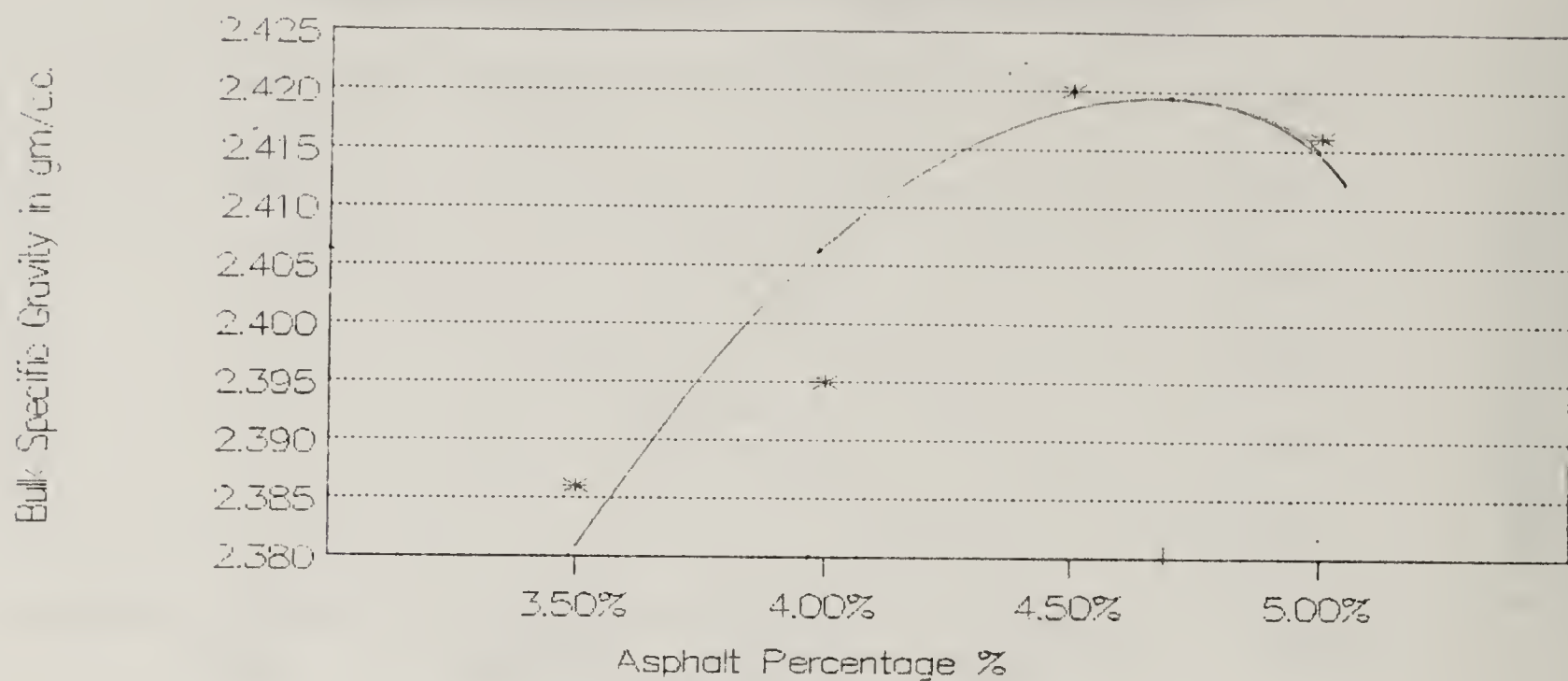


# Polybilt Mod. Conoco - II Gradation Agg

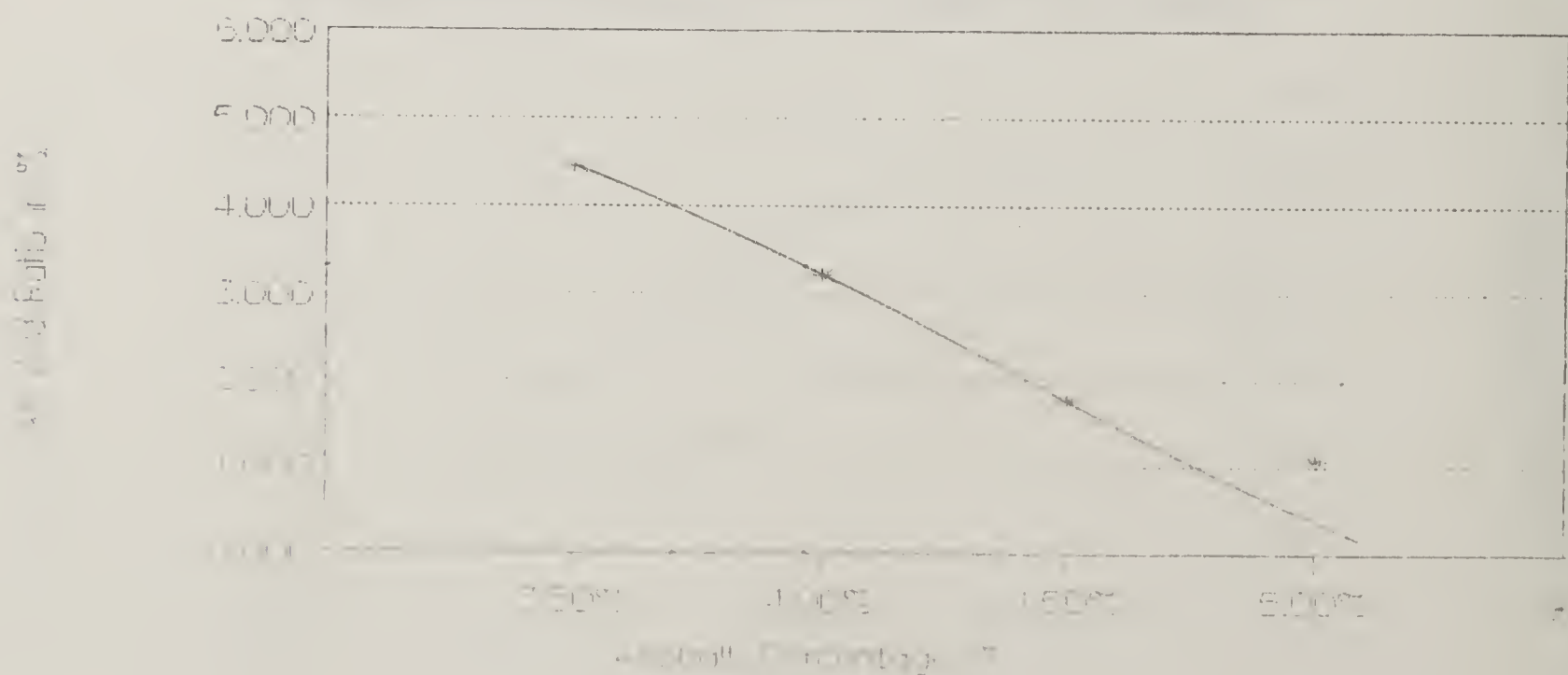
## Mineral Filler - Marshall Stability.



# Polybilt Mod. Conoco — II Gradation Agg Mineral Filler — Bulk Specific Gravity.



# Polybilt Mod. Conoco — II Gradation Agg Mineral Filler — Air Void Ratio in %.





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